

A New Environment for Teaching and Learning Mechanics for Engineering Students

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Abstract — *Mechanics is one of the most important subjects in Physics for engineering. Engineering knowledge requires the right comprehension of Newton's Laws. It means that engineering students have to understand the concept of force and its implications in Newton's Laws. For instance, it means that students should be able to draw the corresponding free body diagram (FBD). In 1992, the Force Concept Inventory (FCI) was presented as a tool that allows to get information about the force concept comprehension as well as the presence of misconceptions in Mechanics. From the academic year 1992-1993 to 2001-2002, more than 1.500 engineering students, from five different Spanish universities have been taking the FCI. The results showed the problems about the comprehension of the concept of force and about the presence of misconceptions. The results are also compared with those published in 1992 for USA students. As a consequence of the problems found, a new method for teaching Mechanics is now proposed. It consists on designing computer simulations based on selected physical phenomena to enhance comprehension of fundamental mechanical concepts like FBD. Each simulation was proposed to the students along with a sheet of paper describing the corresponding physical phenomena. The new activity was carried out in the laboratory, where computers, blackboard, video projector, etc., are permanently installed. All the activities associated to each computer simulation were performed in 60 minutes and three of them were fulfilled, those ones corresponding to Statics, Kinematics and Dynamics. Its suitability was checked by means of the same tool used to find teaching-learning problems, that is, the FCI. The results got were compared with those obtained by the students that had not taken part in the new teaching-learning environment. In the end it has proved to be a valid activity for teaching Mechanics. In this paper it is showed how this new method has been designed and how can it be applied as well as its influence in the comprehension of the concept of force and in the presence of misconceptions in Mechanics. Besides the aforementioned appraisal, the paper also includes the student assessment of the new teaching learning environment.*

Index Terms — *Mechanics, teaching-learning, computer simulations, misconceptions, alternative learning.*

INTRODUCTION

The Force Concept Inventory (FCI) is a test about the Newtonian concept of force presented in 1992 for David Hestenes, Malcolm Wells and Gregg Swackhamer. It is composed of 29 multiple choice questions, that allows to evaluate the state of knowledge and the efficacy of the process of teaching-learning of Mechanics and to detect misconceptions.

It has been given to more than 1.500 high-school USA students and more than 500 university USA students. Since it was translated into Spanish, by the first of the authors of this paper, in the academic year 1992-1993, the FCI has been given to students of engineering of the Universities of León, Cantabria, Valladolid, and Salamanca, as well as the *Universidad Politécnica de Madrid*. The application of the FCI test has been done twice on each population, coinciding the first one of them with the beginning of the course and the second, once the teaching of the Mechanics was ended, to be able to value thus the efficiency of the process of instruction by means of the comparison of the state of knowledge before and after it. The students were asked to answer to each one of the questions giving a brief justification to their answers.

In order to evaluate the results of the test it was decided to include only the students of each population who have done both applications of the FCI proposed. The parameters used to the appraisal were "average percentage of correct answers" (%B) and "index of improvement" (h). The first of one of these parameters represent the average percentage of correct answers of the 29 questions presented for each population and each application of the test, and it is directly related to the level of knowledge of Mechanics of that population at the moment of its application. The second one represents the

improvement of the first of the parameters from the first to the second application of the test and it comes mathematically expressed by:

$$h(\text{index of improvement}) = \frac{(\%B_{2nd\ applic.\ FCI}) - (\%B_{1st\ applic.\ FCI})}{100 - (\%B_{1st\ applic.\ FCI})} \quad (1)$$

This “index of improvement”, related to the FCI results, was already used by the authors of the present paper in the report “*Evaluación del estado de conocimientos de Mecánica en alumnos de primer curso de escuelas de ingeniería*” (March, 2001) and subsequently by R. Steinberg and K. Donnelly in the paper “PER Based Reform at to Multicultural Institution” (February, 2002).

Additionally, for two of those populations, these parameters of evaluation were also determined related to the correct justified answers. The parameters for these ones were “average percentage of correct justified answers” (%B_j) and “index of improvement” (h_j).

In order to keep on the method used in the paper presented at the ICEE 1999, entitled “Misconceptions in Mechanics in first year engineering students” (see reference [4]), the parameter used to measure the presence of misconceptions is again the “frequency of presence of the inventory item X that reflect a misconception” (f[X]). The parameter used to measure the evolution of the presence of misconceptions is “index of evolution of the presence of an inventory item of the FCI, X” (i_X):

- if i_X is an index of increase (i_{1,X}) it is mathematically expressed by:

$$i_{1,X}(\text{index of increase}) = \frac{f(X)_{1st\ applic.\ FCI} - f(X)_{2nd\ applic.\ FCI}}{f(X)_{1st\ applic.\ FCI}} \cdot 100 \quad (2)$$

- if i_X is an index of decrease (i_{2,X}) it is mathematically expressed by:

$$i_{2,X}(\text{index of decrease}) = \frac{f(X)_{2nd\ applic.\ FCI} - f(X)_{1st\ applic.\ FCI}}{100 - f(X)_{1st\ applic.\ FCI}} \cdot 100 \quad (3)$$

Table I contains the relation of misconceptions, according to the Hestenes Taxonomy, that are intended to be corrected by the proposed experience, and the inventory items that reflect each of them.

Table II displays the relation of the reference populations and its corresponding appraisal parameters; it includes the results of the USA students too.

Table III shows the presence of inventory items that reflect the misconceptions that will be treated in the experience and its indexes of evolution (increase/decrease), in the reference populations. It includes too results of the Van Heuvelen university students of “Physics 105” (an interface course intended to prepare students who are academically deficient to take the calculus-based university physics).

From the results obtained by means of the application of the FCI it was deduced a series of lacks that are not correct, at least as it will be desirable during the teaching-learning process: faulty comprehension of Newton’s third law, scarce or nil use of vectorial diagrams, insufficient knowledge of the vectorial character of the magnitudes velocity and acceleration. Besides, a series of misconceptions and its persistence were detected. As a consequence of this, it was decided to design an activity to try to reduce the incidence of the problems detected. In this designed activity a special attention is focused on the concept of force in the context of Mechanics, and particularly of the mechanic of the rigid-body, that constitutes an important part of the subject “*Fundamentos Físicos de la Ingeniería*” (“Core Physics of Engineering”). Among the software that permits the physical simulation of phenomena and, particularly, those related to Mechanics, it was selected *Interactive Physics 2.5* to carry out this experience. This program had already been used as educational tool and the *Escuela Superior y Técnica de Ingenieros Agrónomos* of the *Universidad de León* and in the *Escuela Técnica Superior de Ingenieros Agrónomos* of the *Universidad Politécnica de Madrid*, have been license to use it. It is known the use of the tool *Interactive Physics* in centres such as the Western Washington University (USA), the Royal Institute of Technology (Sweden), the Mississippi State University (USA), etc. Besides, some text books like the Serway include, among its contained problems, some that have been resolved with the aid of simulations with the program aforementioned.

Basically the *Interactive Physics* is a data processing program that allows to create physical simulations of phenomena and to change the parameters that define them, the interface of the results, etc., that is why it can be considered like a virtual lab. The simulations created with this tool can be used like didactic materials. It only permits to simulate phenomena in two dimensions. Another factor to keep in mind is the importance that the practical activities have for the formation of the students of engineering, and the contribution that the simulation software may have.

AIMS

The aims that are planned in this experience are:

- To improve the learning of Mechanics contributing to its comprehension and to the correction of the detected misconceptions
- To reinforce the practical component of Mechanics teaching
- To know the students appraisal of the proposed experience

METHODOLOGY

Design of the practical lessons and simulations

From the educational experience and the results obtained of the FCI, and keeping in mind the availability of the populations to take up in the experience, it was decided to design three practical lessons, each one related to the following parts of Mechanics: Statics, Kinematics and Dynamics. The three practical lessons respond to the same structure which consist of the analysis and resolution of an exercise by the students, its subsequent explanation and verification by the teacher, making use of the simulations prepared in each case and searching the implication of the students in the activity. The practical lessons are thought to be applied in one hour classes.

The basic concepts in the practical lesson of Statics are: the vectorial character of the forces and torques, the equilibrium of the particle and of the rigid-body, the 1st and the 3rd Newton's laws, the reactions in unions and, as a fundamental tool, the free body diagram (FDB). Taking all this into account the practical lesson designed was called "The study of Statics of the rigid-body by means of physical simulations". Figures 1 and 2 represent the exercise selected and some of the most characteristic instants of the simulations created with the Interactive Physics, respectively.

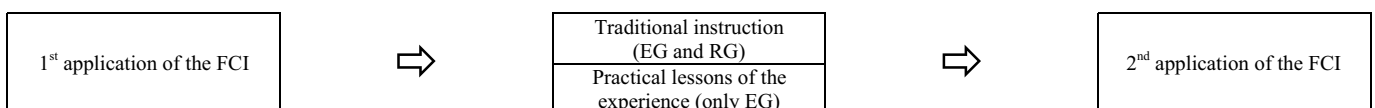
The basic concepts in the practical lesson of Kinematics are: the vectorial character of the magnitudes velocity and acceleration, the temporal derivate of a vector, the characterization of the different types of motions in function of its path and acceleration, and the velocity-acceleration discrimination. Related to the curvilinear motion the practical lesson focuses on the tangential and normal components of the acceleration, the tangential character of the velocity, and the relation between linear and angular magnitudes. The practical lesson designed, thus, was called "The study of Kinematics of the particle by means of physical simulations". Figures 3 and 4 represented the exercise selected and some of the most characteristic instants of the simulations created with the Interactive Physics, respectively.

Finally, the practise of Dynamics called, "The study of Dynamics of the particles by means of physical simulations: 2nd Newton's law and the impulse momentum theorem", contains as basic concepts: the 2nd and the 3rd Newton's laws, the impulse momentum theorem, the restitution coefficient and the types of collisions. Figures 5 and 6 represent the exercise selected and some of the most characteristic instants of the simulations created with the Interactive Physics, respectively.

Planning of the experience

The main criteria to select the populations in which this experience was carried out, was the availability of the professors responsible fro the subjects in which the knowledge of Mechanics is contained. The selection also responded to geographical criteria of proximity, to the affinity of the professors to the activity proposed, and to the technical and material media availability (classrooms, computers, program licenses, etc.). Besides, it was decided to include a population of students of the 2nd degree of LOGSE (the previous course to the University). The populations finally selected to carry out the experience were: *Escuela Superior y Técnica de Ingeniería Agraria* of the *Universidad de León* (Spain), *Escuela Técnica Superior de Ingenieros Agrónomos* of the *Universidad Politécnica de Madrid* (Spain), and *Instituto de Enseñanza Secundaria García Bellido. León* (Spain).

Once selected, each of these populations were divided into two groups of students called experimental (EG) and reference group (RG), respectively. The EG was made up of about 30 students chosen at random and the rest of the students belonged to the RG. Previously to the application of the experience a schedule was set as follows:



In the case of the *Instituto de Enseñanza Secundaria García Bellido. León* it only existed the EG and it was made up of the totality of the students. The resultant was somehow different for this population, to which the practical lessons of the experience were applied at the end of the traditional instruction.

Application of the experience

According to the schedule aforementioned, each of the activities that constituted the experience were carried out: the 1st application of the FCI, the execution of the practical lessons with the data processing application and the 2nd application of the FCI.

Thus, for each one of the experimental populations and in the dates stated, each of the activities of the experience were done. In relation to the FCI test, each student had to answer each of the questions, choosing the option that they considered correct, justifying briefly their choice. During the resolution of the test no additional information was given to them, since it was considered that the information needed to resolve the FCI could be found in it. The time given for the resolution of the FCI was about 90 minutes, giving 30 more minutes to show the instructions about the execution of the test and how to fill in the data of identification.

It took three hours to do the practical lessons with its corresponding simulations, one of them for the Statics practical lesson, one another one for the Kinematics', and the last one for the Dynamics'. These three practical lessons were included in the laboratory plan and, as it has already been said, restricting the participation to the students belonging to the EG. Once the 2nd application of the FCI was performed all the registered students were given the opportunity to carry out the practical lessons based in data processing simulation.

For the execution of the practical lessons included in the experience, the students were arranged in pairs with one PC with the Interactive Physics and the Microsoft Excel installed and with the simulations previously designed. Besides, each student had to attend with the adequate material to resolve of the exercise proposed. The professor directed each practise by means of an elaborated guide, executing the simulation and projecting it on a screen with the aid of a video projector connected to one of the PCs in the laboratory. The statement of each exercise proposed was given to the students when coming into the laboratory. The sequence of actions to do was as follows:

- reading the exercise proposed
- resolution of the exercise
- analysis, resolution and discussion of the results by means of the data processing simulation.

During the development of each practise the professor guided the students, promoting its participation, and managing the timing, so that the pre-arranged time for the practical lesson could be sufficient to do all the activities predicted. The execution of the simulation was done by means of the video projector so that the students could see its development, when they needed, if they found any difficulty in their execution on the computer. In some cases, the results obtained with the running simulation were exported to a spreadsheet in order to analyse it by means of the subsequent graphics (force-time, acceleration-time, velocity-time, position-time, etc.), that contributed to the comprehension of the concepts included in each practise.

The experience with the students of the *Instituto de Enseñanza Secundaria García Bellido. León* was done once the Physics lessons had finished.

As a way to know the appraisal of the experience on the part of students they were submitted to a survey about different aspects of it.

Once the application of the practical lessons to the EG had finished, the 2nd application of the FCI was done by the whole population (EG and RG).

Finally, RG's students carried out the practises.

Collecting data and evaluating results

The results of both applications of the FCI were collected in a spreadsheet in order to determine the parameters of evaluation of each population and of each group (EG and RG). The parameters calculated were the "average percentage of correct answers" (%B) and the "index of improvement" (h).

The results related to the misconceptions were collected in another spreadsheet in order to determine the parameters of evaluation of each population and of each group (EG and RG): the "frequency of presence of the inventory item X that reflects a misconception", that has been called as (f_X), and the "index of evolution of the presence of an inventory item of the FCI, X", which will be identified as i_X . It has to be said that the index of evolution can increase or decrease.

RESULTS

Previous considerations

The results presented subsequently correspond, at first, to those obtained by means of the application of the FCI, and then, to those obtained from the survey done by the students participating in the experience.

The values of the parameters of evaluation obtained for the participating populations in the experience, derived from the application of the FCI, are shown in table IV.

Table V shows the frequencies of presence of the inventory items that reflect the misconceptions treated by the experience ($f[x]$) for the 1st and the 2nd FCI applications, as well as their indexes of evolution (i_x), obtained by the EGs and RGs of the populations participating in the experience. Each one of this inventory items are grouped under the misconception that it reflect (see table I). Thus, it is possible to see at a glance the frequencies of presence of this inventory items and their indexes of evolution, obtained by the groups: *ESyTIA.ULE-EG.2001/2002*, *ESyTIA.ULE-RG.2001/2002*, *ETSIA.UPM-EG.2001/2002*, *ETSIA.UPM-RG.2001/2002* and *IESGB-EG.2001/2002*.

A comparison-summary of the frequencies of presence of the same inventory items that reflect the misconceptions treated by the experience ($f[x]$) for the 1st and the 2nd FCI applications, as well as their indexes of evolution (i_x), obtained by the groups: *ESyTIA.ULE-EG.2001/2002*, *ESyTIA.ULE-RG.2001/2002*, *ETSIA.UPM-EG.2001/2002*, and by the reference populations grouped; are displayed in table VI. The frequencies of presence of this mentioned inventory items obtained by the reference populations grouped is determined as the average of the frequencies of presence belonging to all the reference populations (those that are included in table III). On the same table VI, it is shown the differences between the indexes of evolution (i_x) of each inventory item that reflect a misconception treated by the experience, obtained by the three contrasts proposed:

- EG against RG of the *ESyTIA.ULE.2001/2002*
- EG of the *ESyTIA.ULE.2001/2002* against the reference populations grouped
- EG of the *ETSIA.UPM.2001/2002* against the reference populations grouped

Finally, at the foot of the table VI, the “average” of the differences of the indexes of evolution (i_x) of all the inventory items for which this difference is positive, independent of the contrast analysed, is given. The maximum and the minimum of this same differences are given, too, and the correspondent inventory items are related.

The “average” of the differences of the indexes of evolution (i_x) of all the inventory items for which this difference is negative, independent of the contrast analysed are located at the end, and the maximum and the minimum of this same differences are given, too, and the correspondent inventory items are related.

The RG of the *ETSIA.UPM.2001/2002* are not include in table VI, because of their specials characteristics of size and composition. The EG of the *IESGB.2001/2002* is not include because there are no reference similar for it.

All these values belong to the populations constituted by the students that had done the test the two times that it was proposed.

The validity of the experience proposed is measured by means of the comparison of the indexes of improvement (h) obtained by the experimental groups with the ones reached by the reference groups as well as by comparison of the increasing/decreasing indexes of evolution (i_x) of the presence of the inventory items that reflect the misconceptions treated in the experience. Therefore, this second appraisal was done:

- between the EG against the RG of the *ESyTIA.ULE.2001/2002*
- between the EG of the *ESyTIA.ULE.2001/2002* and the reference population grouped.
- between the EG of the *ETSIA.UPM.2001/2002* and the reference populations grouped.

The criteria to evaluate the influence of the experience in the misconceptions depends on the difference of the increasing/decreasing indexes of evolution (i_x) of the inventory items that reflect the misconceptions obtained by the experimental group, and the one obtained by the reference group or population. It is not mathematically exact to average this indexes of evaluation, because the index of increase has no the same mathematic expression as the index of decrease, but it seems to be valid for comparison.

It is considered that the influence of the experience is positive for an inventory item if the difference of the indexes of evolution (i_x) obtained from the experimental and the reference groups or populations is positive for the three comparisons carried out. If this difference were negative, also for the three comparisons, the influence of the experience could be considered as negative for that inventory item. In those cases that the difference mentioned was positive in a/some comparison/s and negative in the other/s, the influence of the experience on the inventory item will be valued depending on the magnitude of this differences.

For all those inventory items in which the difference of the indexes of evolution were the same, positive or negative, for the three comparisons, it is shown the maximum and the minimum difference and the “average”. Those inventory items that present a low frequency was not included in this evaluation.

Finally, in figure 7 it is represented the index of improvement obtained by the experimental groups and by the reference groups of the population participating in the experience together with the ones reached by the populations aforementioned.

The results of the survey about the experience based in data processing simulations are collected in the table VI. These ones are analysed at the end of this chapter and is also shown a figure about the global appraisal of the experience by the students (figure 9).

Analysis of results

It is necessary to keep in mind the sizes of the different groups to analyse the results. The most significant population of the three submitted to the experience was, of course, the *Escuela Superior y Técnica de Ingeniería Agraria. Universidad de León (ESyTIA.ULE)*, because its groups, EG and RG, had a significant size. It was not the same for the *Escuela Técnica Superior de Ingenieros Agrónomos. Universidad Politécnica de Madrid (ETSIA.UPM)*, since one of its groups (RG) had only seven students; its EG can be considered as significant. The third population, the *Instituto de Enseñanza Secundaria García Bellido. León (IES.AGB)*, had only EG and it can be considered significant because of its size, 22.

Taking all this into account, the index of improvement of the EG of the *ESyTIA.ULE* (0,11) is higher than the RG one of the same population (0,07), so the experience could be considered as academically profitable.

In the case of the *ETSIA.UPM*, the index of improvement of the EG (0,13) is lower than the RG one of the same population, but it could be because of its size and because of its composition. In the EG of the *IES.AGB* the index of improvement is 0,10 but there are no contrast because RG does not exist.

When the results belonging to the medium technical school populations are analysed it can be observed that the index of improvement for the EG of the *ESyTIA.ULE* (0,11) is higher than the value of the index of improvement obtained by *ESyTIA.ULE* in the academic year 1996/1997 (0,06), by *ETSIA.UVA* in the academic year 1999/2000 (-0,02), by *EUITOP.USAL* in the academic year 1999/2000, and by *ESyTIA.ULE* for the academic year 2000/2001 (0,07).

In order to get a second perspective of the academic profit of the experience, the results of the EG in the *ESyTIA.ULE* is compared with the ones belonging to the superior technical school populations. It is observed that the index of improvement of the EG in the *ESyTIA.ULE* is 50% lower than the ones obtained by *ETSICCP.UC* population (0,25) and *ETSII.UVA* population (0,24). Nevertheless, it is a result that could be consider foreseeable. It was also shown, that the index of improvement obtained by the EG in the *ESyTIA.ULE* it is almost 50% higher than the one obtained by *ETSIA.UPM* in the academic year 1997/1998 (0,06), though, it is similar to the one obtained by the EG in the *ETSIA.UPM* (0,13).

Regarding the misconceptions, evaluated by means of the presence and evolution of the inventory items that reflect them, it could be considered that the experience had a positive influence for 11 of them, according to the three comparisons performed. These inventory items were 2a, 6a, 7b, 7c, 11d, 13d, 17b, 18d, 20a, 25a and 28e. The maximum difference between the indexes of evolution (i_x) of the reference and the experimental group was [100,0 - (-0,7)]; the minimum, (28,3 - 23,3) and the “average” was 38,8 (see table VI). It can be considered that the experience had a negative influence for 5 of the inventory items. These inventory items were: 12b, 14b, 15b, 20c and 24 b. The maximum difference between the indexes of evolution (i_x) of the reference and the experimental group was [38,3 - (-4,0)]; the minimum, [-8,8 - (-5,8)] and the “average” was 23,1 (see table VI).

For the 8 remaining inventory items: 13b, 15a, 20d, 21b, 21c, 22a, 26c and 29a, the difference between the indexes of evolution was positive in some comparisons and negative in the others. For the 13b, 15a and 21c the influence seems to be positive, for the 20d and 21b, negative; and for the 22a, 26c and 29a the difference vary a lot from one comparison to another (see table VI).

The inventory items that presented a low frequency and for this reason were not included in this evaluation were: 2d, 11b, 12e, 14d, 20b and 28a (see table VI). The survey about the experience proposed to the students has many favourable results as it is shown (see table VI). Thus, from the 79 students that participated in all the activities of the experience, 69% of them valued it as “very high” (15%) or “high” (54%). About the methodology applied in the experience, 99% valued it as “very adequate” (62%) or “adequate” (37%).

The same survey shows the concepts that the students consider to have improved, being the ones that appear with more frequency: Newton’s laws, free body diagram, diagrams of forces, tangential and normal acceleration and its intrinsic components, the momentum theorem, restitution coefficient, reactive forces and contact forces. Improving the comprehension of these concepts was one of the aims of the practical lessons and the survey shows that this goal was also reached in the opinion of the students.

CONCLUSIONS

The analysis of the results obtained by means of the execution of the proposed experience, evaluated through the FCI, permits to affirm that an improvement in the comprehension of the Mechanics has been obtained.

The analysis of the results about the misconceptions permits to affirm that the influence was positive for (11+3) inventory items of those treated by the proposed experience; nevertheless, (5+2) of these inventory items showed a negative influence due to the experience. Other 3 inventory items treated by the experience showed positive or negative influence depending on the comparison carried out.

The appraisal of the experience on the part of the participant students has been positive in all the aspects, being significant that the own students have been able to indicate, without any indications, in what concepts of Mechanics they had observed an improvement in comprehension because of the experience applied.

Thus, it is deduced that the experience could be considered as academically profitable, so it could be incorporated to the ordinary didactic activities that are planned and applied to increase the learning of Mechanics.

The experience has supposed, besides, a reinforcement of the practical component of the teaching in Mechanics, incorporating a new methodology and new unusual educational material, that requires a greater implication of the students in the teaching-learning process.

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FIGURES AND TABLES

TABLE I

RELATION OF MISCONCEPTIONS, ACCORDING TO THE HESTENES TAXONOMY, THAT ARE INTENDED TO BE CORRECTED BY THE PROPOSED EXPERIENCE, AND THE INVENTORY ITEMS THAT REFLECT EACH OF THEM.

Misconception	Description	Inventory items
AF.1	only active agents exert forces	11b; 12b; 13d; 14d; 15a,b; 18d; 22a
AF.2	motion implies active force	29a
AF.3	no motion implies no force	12e
AF.4	velocity proportional to applied force	25a; 28a
AF.5	acceleration implies increasing forces	17b
AR.1	greater mass implies greater force	2a,d; 11d; 13b; 14b
K.1	position-velocity undiscriminated	20b,c,d
K.2	velocity-acceleration indiscriminated	20a; 21b,c
K.3	non vectorial velocity composition	7c
CI.3	last force to act determines motion	6a; 7b; 24b; 26c
R.3	resistance opposes force/impetus	28e

TABLE II

RELATION OF REFERENCE POPULATIONS AND THEIR CORRESPONDING APPRAISAL PARAMETERS

Population	Academic year	Population sizes			% of correct answers		Index of improvement (h)
		1 st appl.	2 nd appl.	1st and 2 nd appl.	1 st appl.	2 nd appl.	
EUITA.ULE	1992/1993	248	104	90	39,81	49,92	0,17
ESyTIA.ULE	1993/1994	168	53	38	43,28	52,36	0,16
ESyTIA.ULE	1996/1997	235	127	83	35,98	39,76	0,06
ETSIA.UPM	1997/1998	86	45	43	51,56	54,45	0,06
ETSICCP.UC	1997/1998	132	195	86	59,14	69,17	0,25
ETSIA.UVA	1999/2000	59	21	17	34,08	32,45	-0,02
EPSZOP.USAL	1999/2000	67	17	15	37,47	42,30	0,08
ETSIL.UVA	2000/2001	125	20	17	50,71	62,47	0,24
ESyTIA.ULE	2000/2001	206	107	96	35,88	40,19	0,07
TOTAL		1326	689	485			
Arizona AP				33	41,00	57,00	0,27
Swackhamer AP				11	73,00	85,00	0,44
Van Heuvelen 105				116	34,00	63,00	0,44
Wells 105				44	36,00	68,00	0,50
Arizona State Reg.				139	52,00	63,00	0,23
TOTAL				343			

Population	Academic year	Population sizes			% of correct <u>justified</u>		Index of improvement (h)
		1 st appl.	2 nd appl.	1st and 2 nd appl.	1 st appl.	2 nd appl.	
EUITA.ULE	1992/1993	248	104	90	31,46	44,29	0,19
ESyTIA.ULE	1996/1997	235	127	83	25,92	32,28	0,09
TOTAL		483	231	173			

The percentages of correct answers and the indexes of improvement that are shown correspond to the subpopulations of students that have done the both proposed applications of the FCI.

Acronyms and names used and their corresponding academic centres or populations

EUITA.ULE	<i>Escuela Universitaria de Ingenieros Técnicos Agrícolas</i> (the old ESyTIA.ULE). <i>Universidad de León</i> (Spain)
ESyTIA.ULE	<i>Escuela Superior y Técnica de Ingeniería Agraria. Universidad de León</i> (Spain)
ETSIA.UPM	<i>Escuela Técnica Superior de Ingenieros Agrónomos. Universidad Politécnica de Madrid</i> (Spain)
ETSICCP.UC	<i>Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos. Universidad de Cantabria</i> (Spain)
ETSIA.UVA	<i>Escuela Técnica Superior de Ingenierías Agrarias. Universidad de Valladolid</i> (Spain)
EPSZOP.USAL	<i>Escuela Politécnica Superior de Zamora (Titulación de Ingeniería de Obras Públicas). Universidad de Salamanca</i> (Spain)
ETSIL.UVA	<i>Escuela Técnica Superior de Ingenieros Industriales. Universidad de Valladolid</i> (Spain)
Arizona AP	Arizona high schools students of second year "Advanced Placement" physics course (USA)
Swackhamer AP	Swackhamer high schools students of second year "Advanced Placement" physics course (USA)
Van Heuvelen 105	Van Heuvelen and Wells university students of "Physics 105", an interface course intended to prepare students who are academically deficient to take the university physics (USA); <u>a experimental method has been given to them</u>
Wells 105	
Arizona State Reg.	Arizona State University students of the same "Physics 105" (USA), by conventional methods

TABLE III

PRESENCE AND EVOLUTION OF INVENTORY ITEMS THAT REFLECT THE MISCONCEPTIONS THAT WILL BE TREATED IN THE EXPERIENCE, IN THE REFERENCE POPULATIONS

Population	Academic year	Misconceptions treated																																
		AF.1															AF.2			AF.3														
		11b			12b			13d			14d			15a			15b			18d			22a			29a			12e					
		f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x
Van Heuvelen 105		19	4	79	29	92	-89	4	0	100	6	0	100	16	23	-8	16	38	-26	8	2	75	3	34	-32	12	17	-6	3	0	100			
ESyTIA.ULE	1992/1993	4	1	75	74	72	3	7	2	71	2	3	-1	27	21	22	26	28	-3	1	1	0	6	14	-9	29	28	3	4	2	50			
ESyTIA.ULE	1993-1994	5	0	100	74	82	-31	11	5	55	5	3	40	8	24	-17	34	32	6	8	3	63	5	13	-8	32	29	9	3	3	0			
ESyTIA.ULE	1996/1997	10	5	50	68	70	-6	5	7	-2	2	5	-3	25	17	32	24	29	-7	1	8	-7	10	11	-1	14	13	7	7	4	43			
ETSIA.UPM	1997/1998	2	0	100	77	86	-39	2	2	0	0	0	0	23	28	-6	35	30	14	7	5	29	16	14	13	12	16	-5	2	0	100			
ETSICCP.UC	1997/1998	2	1	50	80	74	8	5	6	-1	1	1	0	27	23	15	22	40	-23	1	7	-6	15	27	-14	13	13	0	1	2	-1			
ETSIA.UVA	1999/2000	0	12	-12	65	65	0	12	12	0	6	0	100	6	29	-24	29	24	17	0	6	-6	6	12	-6	24	24	0	6	12	-6			
EUITOP.USAL	1999/2000	13	7	46	73	67	8	13	0	100	0	0	0	27	20	26	40	33	18	0	0	0	7	13	-6	13	13	0	20	20	0			
ETSH.UVA	2000-2001	6	0	100	76	88	-50	6	0	100	0	0	0	24	12	50	24	35	-14	0	0	0	6	12	-6	18	6	67	6	6	0			
ESyTIA.ULE	2000-2001	7	3	57	72	65	10	4	0	100	2	0	100	18	28	-12	30	29	3	3	4	-1	6	13	-7	14	16	-2	3	1	67			

Population	Academic year	Misconceptions treated																													
		AF.4						AR.1						K.1																	
		25a		28a		2a		2d		11d		13b		14b		20b		20c		20d											
		f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x						
Van Heuvelen 105		13	28	-17	12	11	8	72	23	68	0	0	0	51	21	59	13	2	85	4	0	100	5	6	-1	9	11	-2	38	17	55
ESyTIA.ULE	1992/1993	39	34	13	1	1	0	34	36	-3	0	0	0	31	29	6	68	74	-19	6	2	67	1	1	0	3	2	33	22	17	23
ESyTIA.ULE	1993-1994	34	11	68	8	8	0	53	39	26	0	0	0	34	32	6	71	63	11	5	8	-3	0	5	-5	8	3	63	18	13	28
ESyTIA.ULE	1996/1997	37	30	19	6	4	33	56	54	4	0	1	-1	39	32	18	65	71	-17	8	8	0	0	2	-2	4	11	-7	31	27	13
ETSIA.UPM	1997/1998	16	23	-8	2	5	-3	74	35	53	0	0	0	33	30	9	58	47	19	5	0	100	0	2	-2	7	21	-15	2	2	0
ETSICCP.UC	1997/1998	23	23	0	2	0	100	50	19	62	0	0	0	24	5	79	52	42	19	2	1	50	0	0	0	19	14	26	5	1	80
ETSIA.UVA	1999/2000	35	24	31	0	0	0	47	59	-23	0	0	0	24	47	-30	59	59	0	6	0	100	0	0	0	24	47	-30	6	0	100
EUITOP.USAL	1999/2000	20	13	35	7	13	-6	53	53	0	0	0	0	7	27	-22	60	67	-18	7	7	0	0	0	0	20	33	-16	0	7	-7
ETSH.UVA	2000-2001	6	18	-13	0	0	0	24	29	-7	0	0	0	29	29	0	24	41	-22	0	0	0	0	0	0	24	18	25	0	0	0
ESyTIA.ULE	2000-2001	35	34	3	2	2	0	69	61	12	0	0	0	48	47	2	65	70	-14	4	3	25	1	0	100	25	33	-11	7	3	57

Population	Academic year	Misconceptions treated																													
		AF.5				K.2				K.3				CI.3				R.3													
		17b		20a		21b		21c		7c		6a		7b		24b		26c		28e											
		f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x									
Van Heuvelen 105		23	19	17	21	9	57	8	2	75	39	11	72	25	17	32	37	23	38	39	28	28	18	13	28	26	21	19	3	0	100
ESyTIA.ULE	1992/1993	23	27	-5	14	10	29	4	4	0	21	16	24	14	10	29	31	32	-1	30	30	0	27	31	-5	27	28	-1	2	0	100
ESyTIA.ULE	1993-1994	18	18	0	29	16	45	5	3	40	16	18	-2	16	13	19	24	39	-20	24	42	-24	26	24	8	26	13	50	8	0	100
ESyTIA.ULE	1996/1997	35	37	-3	13	10	23	2	2	0	19	21	-2	24	23	4	25	32	-9	25	26	-1	31	32	-1	23	33	-13	7	7	0
ETSIA.UPM	1997/1998	7	14	-8	28	7	75	2	0	100	28	16	43	28	19	32	26	21	19	30	26	13	14	19	-6	30	40	-14	2	0	100
ETSICCP.UC	1997/1998	12	6	50	9	7	22	2	2	0	19	10	47	16	14	13	22	14	36	19	7	63	13	10	23	38	30	21	1	3	-2
ETSIA.UVA	1999/2000	29	24	17	12	18	-7	6	6	0	12	24	-14	6	12	-6	12	-4	47	-10	24	35	-14	35	18	49	53	53	0	0	12
EUITOP.USAL	1999/2000	33	33	0	27	20	26	0	0	0	33	13	61	13	27	-16	40	33	18	27	27	0	20	13	35	47	40	15	7	0	100
ETSH.UVA	2000-2001	6	12	-6	18	18	0	6	0	100	24	18	25	29	24	17	24	24	0	18	6	67	18	6	67	24	41	-22	6	0	100
ESyTIA.ULE	2000-2001	25	23	8	22	19	14	2	5	-3	23	23	0	14	14	0	42	44	-3	25	35	-13	27	31	-5	34	40	-9	14	5	64

f[x]₁ and f[x]₂ are the frequencies of presence of the inventory item "x" for the 1st and the 2nd applications of the FCI, respectively; i_x is the index of evolution of the presence of the inventory item "x"

TABLE IV

RELATION OF EXPERIMENTAL POPULATIONS AND THEIR CORRESPONDING APPRAISAL PARAMETERS

Population	Academic year	Population sizes			% of correct answers		Index of improvement
		1 st appl.	2 nd appl.	1st and 2 nd appl.	1 st appl.	2 nd appl.	(h)
ESyTIA. ULE	2001/2002	106	83	56	34,98	40,46	0,08
ESyTIA. ULE - EG				15	27,82	35,86	0,11
ESyTIA. ULE - RG				41	37,59	42,14	0,07
ETSIA. UPM	2001/2002	68	41	39	36,78	45,98	0,15
ETSIA. UPM - EG				32	36,53	45,04	0,13
ETSIA. UPM - RG				7	37,93	50,25	0,20
IES. G.B.	2001/2002	26	24	22	46,39	51,57	0,10
IES. G.B. - EG				22	46,39	51,57	0,10
IES. G.B. - RG				0			
TOTAL		295	148	117			

The percentages of correct answers and the indexes of improvement that are shown correspond to the subpoblaciones of students that have done the both proposed applications of the FCI inside each population.

Acronyms utilized and its corresponding academic centres

ESyTIA. ULE	Escuela Superior y Técnica de Ingeniería Agraria. Universidad de León (Spain)
ETSIA. UPM	Escuela Técnica Superior de Ingenieros Agrónomos. Universidad Politécnica de Madrid (Spain)
IES. G.B.	Instituto de Enseñanza Secundaria García Bellido. MEyC. León (Spain)

TABLE V

PRESENCE AND EVOLUTION OF INVENTORY ITEMS THAT REFLECT THE MISCONCEPTIONS TREATED IN THE EXPERIENCE, IN THE EXPERIMENTAL POPULATIONS

Population	Academic year	Misconceptions treated																													
		AF.1																		AF.2			AF.3								
		11b			12b			13d			14d			15a			15b			18d			22a			29a			12c		
		f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x
ESyTIA.ULE-EG	2001/2002	7	5	29	60	79	-48	7	2	71	7	4	43	40	21	48	13	41	-32	20	4	80	7	16	-10	27	32	-7	7	2	71
ESyTIA.ULE-RG	2001/2002	2	5	-3	76	79	-13	5	2	60	0	4	-4	24	21	13	22	41	-24	5	4	20	12	16	-5	27	32	-7	0	2	-2
ETSIA.UPM-EG	2001/2002	19	3	84	59	79	-49	16	5	69	0	0	0	22	28	-8	9	38	-32	3	0	100	3	3	0	47	38	19	0	0	0
ETSIA.UPM-RG	2001/2002	14	3	79	71	79	-28	0	5	-5	0	0	0	14	28	-16	71	38	46	0	0	0	0	3	-3	29	38	-13	0	0	0
IES.G.B.-EG	2001/2002	5	0	100	86	77	10	18	9	50	14	0	100	14	14	0	36	45	-14	9	5	44	5	9	-4	14	9	36	5	0	100

TABLE VI

COMPARISON OF THE PRESENCE AND EVOLUTION OF INVENTORY ITEMS THAT REFLECT THE MISCONCEPTIONS TREATED IN THE EXPERIENCE, BETWEEN REFERENCES AND EXPERIMENTAL GROUPS

Population	Academic year	Misconceptions treated																													
		AF.1																		AF.2			AF.3								
		11b			12b			13d			14d			15a			15b			18d			22a			29a			12c		
		f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x	f[x] ₁	f[x] ₂	i _x
Reference populations grouped		6.8	3.3	51.5	68.8	76.1	-23.4	6.9	3.4	50.7	2.4	1.2	50.0	20.1	22.5	-3.0	28.0	31.8	-5.3	2.9	3.6	-0.7	8.0	16.3	-9.0	18.1	17.5	3.3	5.5	5.0	9.1
ESyTIA.ULE-RG	2001/2002	2.0	5.0	-3.1	76.0	79.0	-12.5	5.0	2.0	60.0	0.0	4.0	-4.0	24.0	21.0	12.5	22.0	41.0	-24.4	5.0	4.0	20.0	12.0	16.0	-4.5	27.0	32.0	-6.8	0.0	2.0	-2.0
ESyTIA.ULE-EG	2001/2002	7.0	5.0	28.6	60.0	79.0	-47.5	7.0	2.0	71.4	7.0	4.0	42.9	40.0	21.0	47.5	13.0	41.0	-32.2	20.0	4.0	80.0	7.0	16.0	-9.7	27.0	32.0	-6.8	7.0	2.0	71.4
ETSIA.UPM-EG	2001/2002	19.0	3.0	84.2	59.0	79.0	-48.8	16.0	5.0	68.8	0.0	0.0	0.0	22.0	28.0	-7.7	9.0	38.0	-31.9	3.0	0.0	100.0	3.0	3.0	0.0	47.0	38.0	19.1	0.0	0.0	0.0
(1)				31.6			-35.0			11.4			46.9			35.0			-7.8			60.0			-5.1			0.0			73.4
(2)				-22.9			-24.1			20.7			-7.1			50.5			-26.9			80.7			-0.7			-10.2			62.3
(3)				32.7			-25.4			18.0			-50.0			-4.7			-26.6			100.7			9.0			15.8			-9.1

TABLE VII

RESULTS OF THE SURVEY ABOUT THE EXPERIENCE

RESULTS OF THE SURVEY ABOUT THE EXPERIENCE														
Participating population in the experience										93				
Population that have done all the activities of the experience: 1 st and 2 nd application of the FCI and the three practises										79				
Population that have done the survey about the experience										87				
Results of the survey about the experience		Answers												
		abs	%	abs	%	abs	%	abs	%	abs	%			
about the knowledge level required		very high		high		adecuate		low		very low				
		Practise n° 1: Statics	3	3%	19	22%	61	70%	2	2%	2	2%		
		Practise n° 2: Kinematics	3	3%	30	34%	51	59%	2	2%	1	1%		
		Practise n° 3: Dynamics	3	3%	17	20%	58	67%	8	9%	1	1%		
about the improvement of the comprehension of the concepts of Mechanics implicated		very high		high		adecuate		low						
		Practise n° 1: Statics	7	8%	67	77%	11	13%	2	2%				
		Practise n° 2: Kinematics	14	16%	55	63%	18	21%	0	0%				
		Practise n° 3: Dynamics	15	17%	64	74%	8	9%	0	0%				
concept and/or principles that they consider its comprehension have improved		concepts or principles									frequency			
		Practise n° 1: Statics		free body diagram									28	
				diagram of forces									17	
				equilibrium									4	
				torques determination									3	
				concept of force									1	
				Newton's laws									8	
				reactive forces									4	
		Practise n° 2: Kinematics		tangential and normal acceleration									8	
				concepts of Kinematics									9	
				kinds of motions									1	
				intrinsic components									13	
				circular uniform motion									10	
				rectilinear uniform motion									2	
				angular and linear magnitudes									1	
				motion ecuations									1	
				velocity and acceleration graphics									2	
		Practise n° 3: Dynamics		relation between velocity and acceleration									1	
				Newton's laws									30	
				momentum theorema									14	
restitution coeficient									25					
contact force									5					
types of collisions									3					
kinds of motions									1					
velocity determination									1					
diagram of forces									1					
appraisal of the methodology used		very adecuate		adecuate		low adecuate								
		54	62%	32	37%	1	1%							
appraisal of the fact of doingt the practises alone or accompanying		olone		accompanying										
		4	5%	83	95%									
global appraisal of the activity		very high		high		adecuate		low		very low				
		13	15%	47	54%	24	28%	0	0%	3	3%			
consierations about the experience		considerations									frequency			
		it contributes to improve the comprehension									4			
		more time is needed for explanations									2			
		more time is needed for play with the computers									2			
		more time is needed for the resolution of the exercises									3			
		practises should be spread in a longer period of time									1			
		everything is correct									6			
		practises should be simultaneated with classes									3			
		well structured contains									1			
		well choosen contains									1			
		it should be studied the armonic motion									2			
		it should be studied mechanics of fluids									3			
		it should be studied pendular motion									1			
		is it possible to use erroneus data in the simulations?									1			
		more real practises than virtual ones									1			
		virtual practises are not profitable									1			

FIGURE 1

PROPOSED EXERCISE IN THE PRACTISE “THE STUDY OF STATICS OF THE RIGID–BODY BY MEANS OF PHYSICAL SIMULATIONS”.

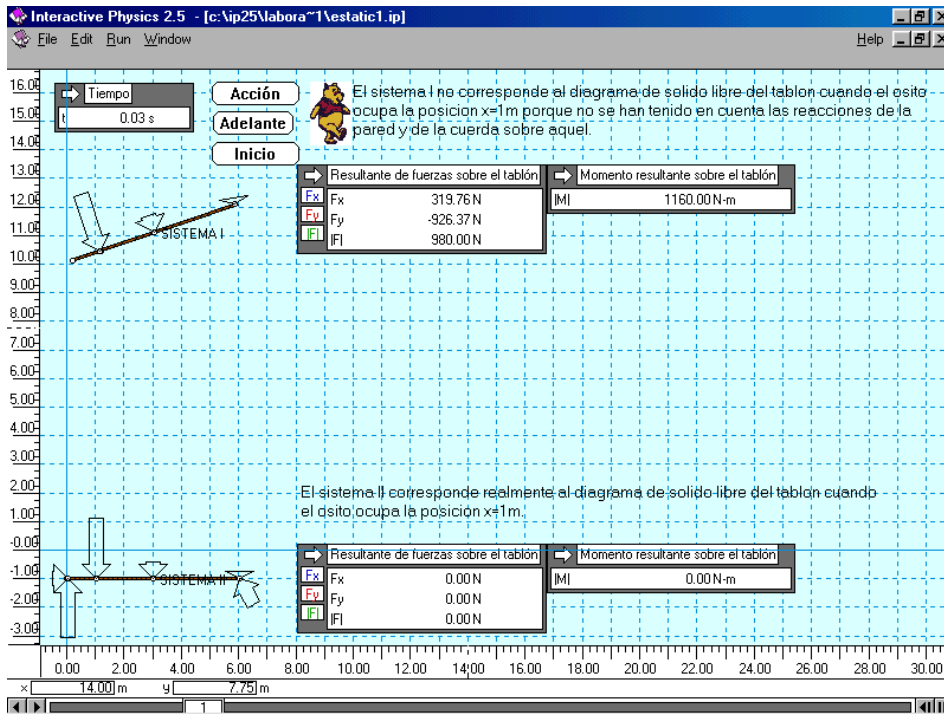
PRÁCTICA Nº1: Estudio de la estática del sólido rígido mediante simulaciones físicas

Nombre: Apellidos:
 Titulación: Plan: Duración de la práctica: 1 hora.

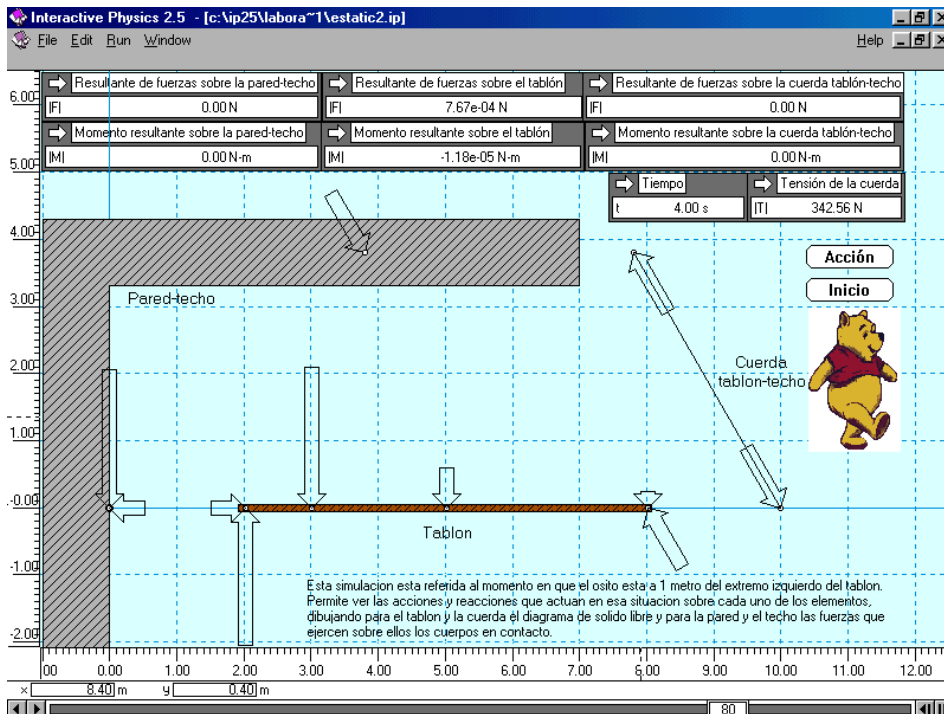
ENUNCIADO DEL EJERCICIO	FIGURA
<p>Un osito hambriento de 700 N de peso camina sobre un tablón con la intención de coger un barril de miel que cuelga de su extremo. El tablón pesa 200 N y mide 6 m de longitud, y está articulado en su unión con la pared y suspendido por una cuerda en el extremo izquierdo. La cuerda que une el extremo del tablón con el techo forma un ángulo de 60 grados con aquel y puede soportar una tensión de 900 N. El barril de miel pesa 80 N.</p> <ol style="list-style-type: none"> 1. Dibujar el diagrama de sólido libre del tablón cuando el osito se encuentra a 1 m de la pared. 2. Dibujar el diagrama de sólido libre de la cuerda, así como las fuerzas ejercen el tablón sobre la pared y la cuerda sobre el techo. 3. Calcular la tensión de la cuerda y las componentes de la reacción en la articulación cuando el osito se encuentra a 1 m de la pared. 4. Determinar si el osito podrá llegar a coger el barril de miel y en caso contrario a qué distancia del extremo del tablón podrá llegar antes de que se rompa la cuerda que lo sujeta. 	

FIGURE 2

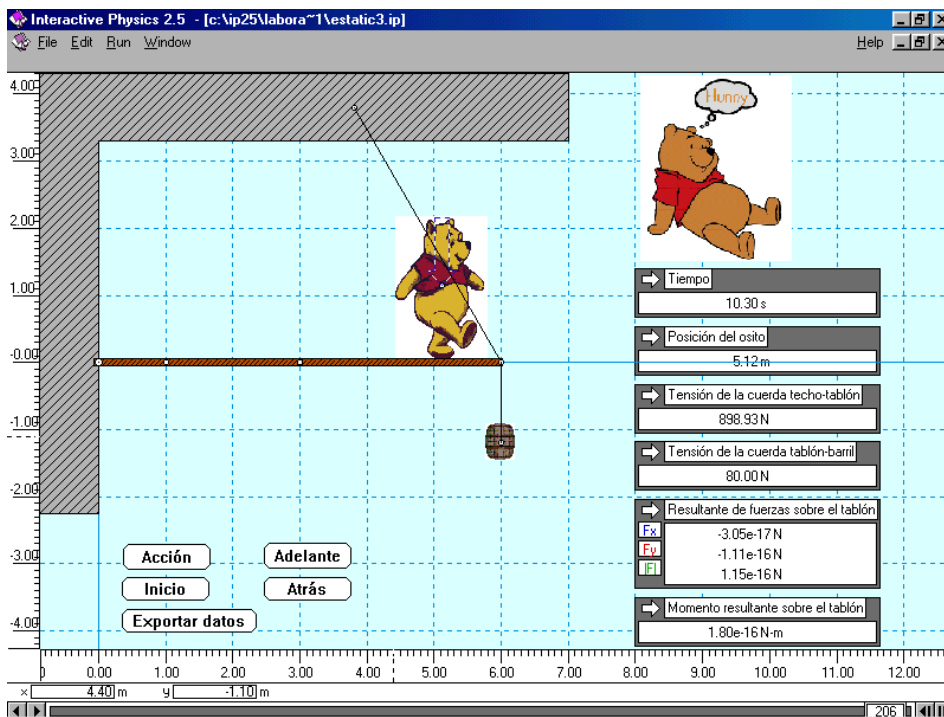
MOST CHARACTERISTIC INSTANTS OF THE SIMULATION CONTAINED IN THE PRACTISE “THE STUDY OF STATICS OF THE RIGID–BODY BY MEANS OF PHYSICAL SIMULATIONS”.



Instant $t=0,03$ s of the simulation *estatic1.ip*.



Instant $t=4,00$ s of the simulation *estatic2.ip*.



Instant $t=10,30$ s of the simulation *estatic3.ip*.

FIGURE 3

PROPOSED EXERCISE IN THE PRACTISE “THE STUDY OF KINEMATICS OF THE PARTICLE BY MEANS OF PHYSICAL SIMULATION”.

PRÁCTICA Nº2: Estudio de la cinemática de partículas mediante simulaciones físicas

Nombre: Apellidos:
 Titulación: Plan: Duración de la práctica: 1 hora.

ENUNCIADO DEL EJERCICIO

Un disco (A) de 4 m de radio gira en sentido contrario a las agujas del reloj a una velocidad uniforme de 30 r.p.m. Dicho disco está unido a una biela (BC) en el punto B mientras que el otro extremo de la biela lo está a una deslizadera (C) que se mueve horizontalmente. En un instante determinado del movimiento del sistema éste ocupa la posición de la figura.

1. Dibujar la velocidad y la aceleración del punto B en la posición que representa la figura, cuando el disco haya girado 135°, cuando haya girado 270° y cuando vuelva a ocupar la posición de la figura. (Representar cada situación de forma independiente)
2. Clasificar el movimiento del punto B.
- 3.1. Expresar vectorialmente la velocidad del punto B, en coordenadas cartesianas y en coordenadas intrínsecas, para la posición representada en la figura y para las posiciones que ocupe el punto B cuando el disco haya girado 135° y 270°, respectivamente.
- 3.2. Expresar vectorialmente la aceleración del punto B, en coordenadas cartesianas y en coordenadas intrínsecas, para la posición representada en la figura y para las posiciones que ocupe el punto B cuando el disco haya girado 135° y 270°, respectivamente.
4. Teniendo en cuenta la definición de aceleración: $a = \dot{v}$, justificar los valores calculados, en coordenadas intrínsecas, de la aceleración y de la velocidad del punto B.
- 5.1. Dibujar la velocidad de la deslizadera en la posición representada en la figura.
- 5.2. Dibujar el sistema en la posición en que por primera vez se anula la velocidad de la deslizadera.
- 5.3. Dibujar la velocidad de la deslizadera en la posición en la que el disco haya girado 180°.
- 5.4. Dibujar la aceleración de la deslizadera en la posición que ocupa la primera vez que se anula su velocidad.

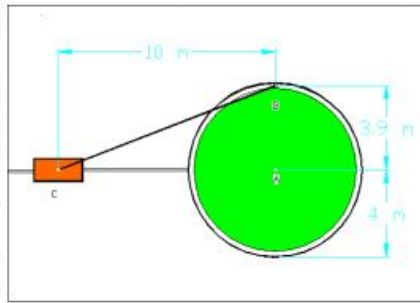
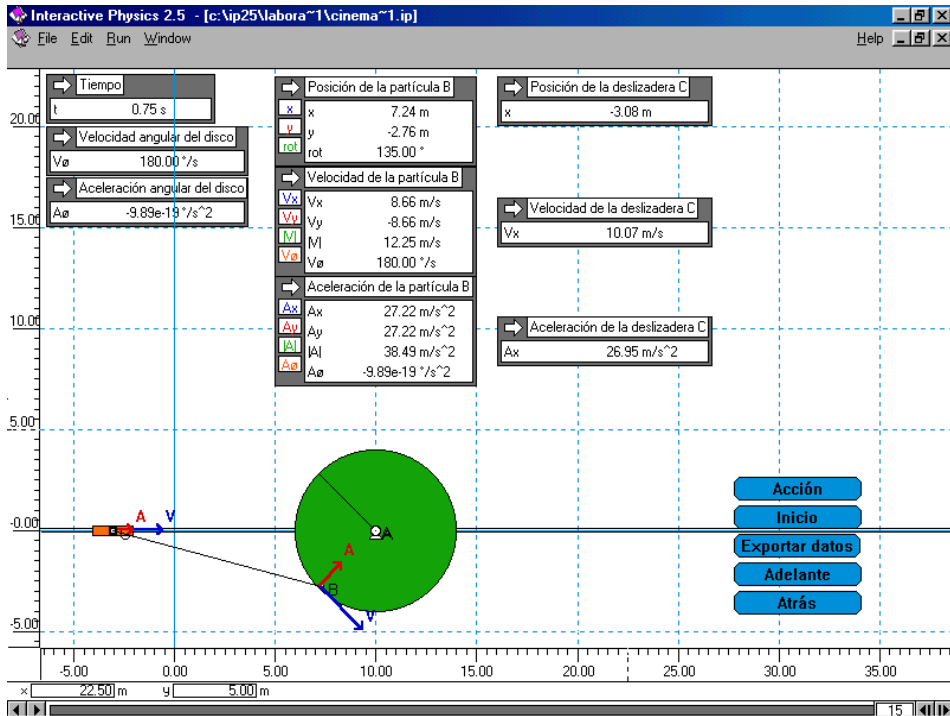


FIGURE 4

MOST CHARACTERISTIC INSTANTS OF THE SIMULATION CONTAINED IN THE PRACTISE “THE STUDY OF KINEMATICS OF THE PARTICLE BY MEANS OF PHYSICAL SIMULATION”.



Instant t=0,75 s of the simulation *cinemati.ip*.

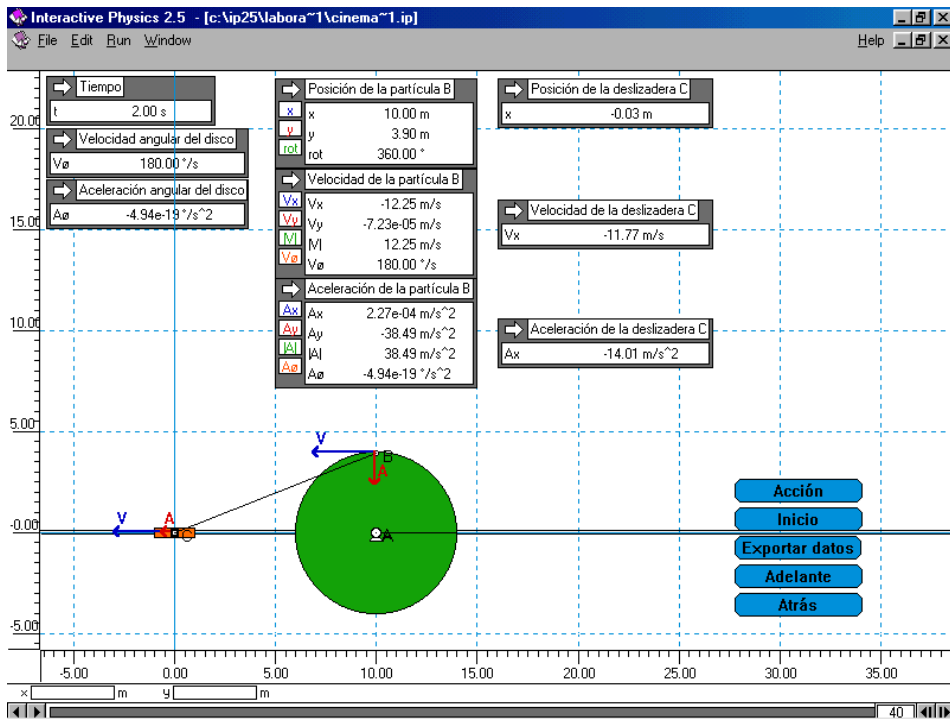


FIGURE 5

PROPOSED EXERCISE IN THE PRACTISE “THE STUDY OF DYNAMICS OF THE PARTICLES BY MEANS OF PHYSICAL SIMULATIONS: 2ND NEWTON’S LAW AND THE IMPULSE MOMENTUM THEOREME”.

PRÁCTICA N°3: Estudio de la dinámica de partículas mediante simulaciones físicas: 2ª Ley de Newton y teorema de la cantidad de movimiento

Nombre: Apellidos:
 Especialidad: Plan: Duración de la práctica: 1 hora.

ENUNCIADO DEL EJERCICIO

Dos bloques A y B, de masas 0,6 kg y 0,9 kg respectivamente, se deslizan sin rozamiento sobre una superficie horizontal. El bloque A, con velocidad inicial nula, está separado del bloque B, una distancia de 20 m (medida entre sus centros de masas), cuando sobre él comienza a actuar una fuerza F de 12 N y dirigida hacia la derecha; esta fuerza se mantiene durante 2 s. Sabiendo que la velocidad del bloque B es de 2 m/s y dirigida hacia la izquierda, determinar las velocidades de ambos bloques antes y después del choque, para los casos en los que el coeficiente de restitución (e) valga: 0, 0,75 y 1, respectivamente.

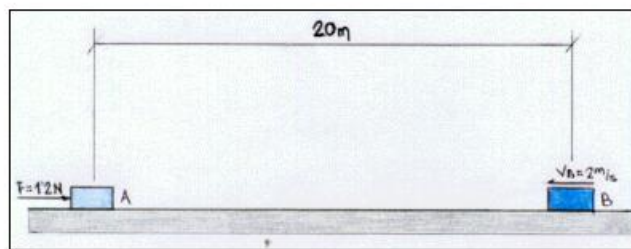


FIGURE 6

MOST CHARACTERISTIC INSTANTS OF THE SIMULATION CONTAINED IN THE PRACTISE “THE STUDY OF DYNAMICS OF THE PARTICLES BY MEANS OF PHYSICAL SIMULATIONS: 2ND NEWTON’S LAW AND THE IMPULSE MOMENTUM THEOREME”.

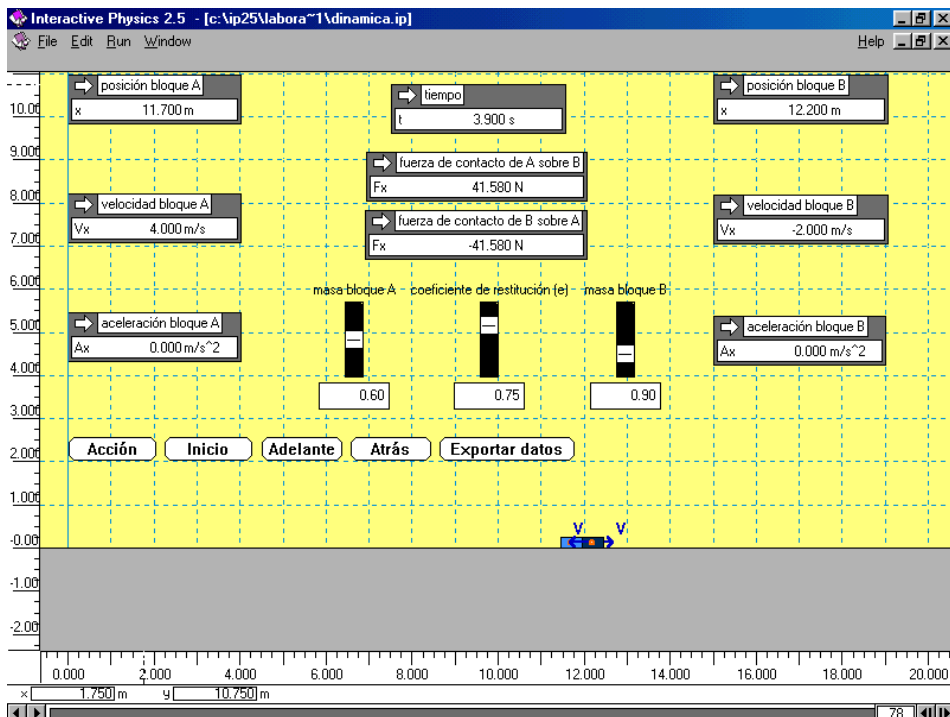
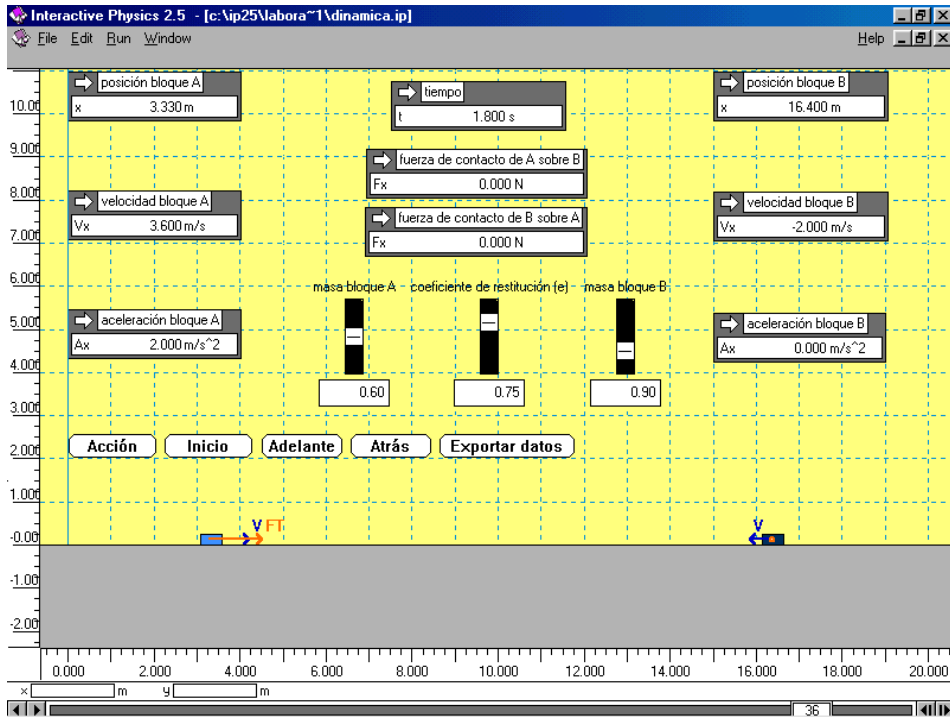


FIGURE 7

INDEXES OF IMPROVEMENT OF EXPERIMENTAL AND REFERENCE POPULATIONS.

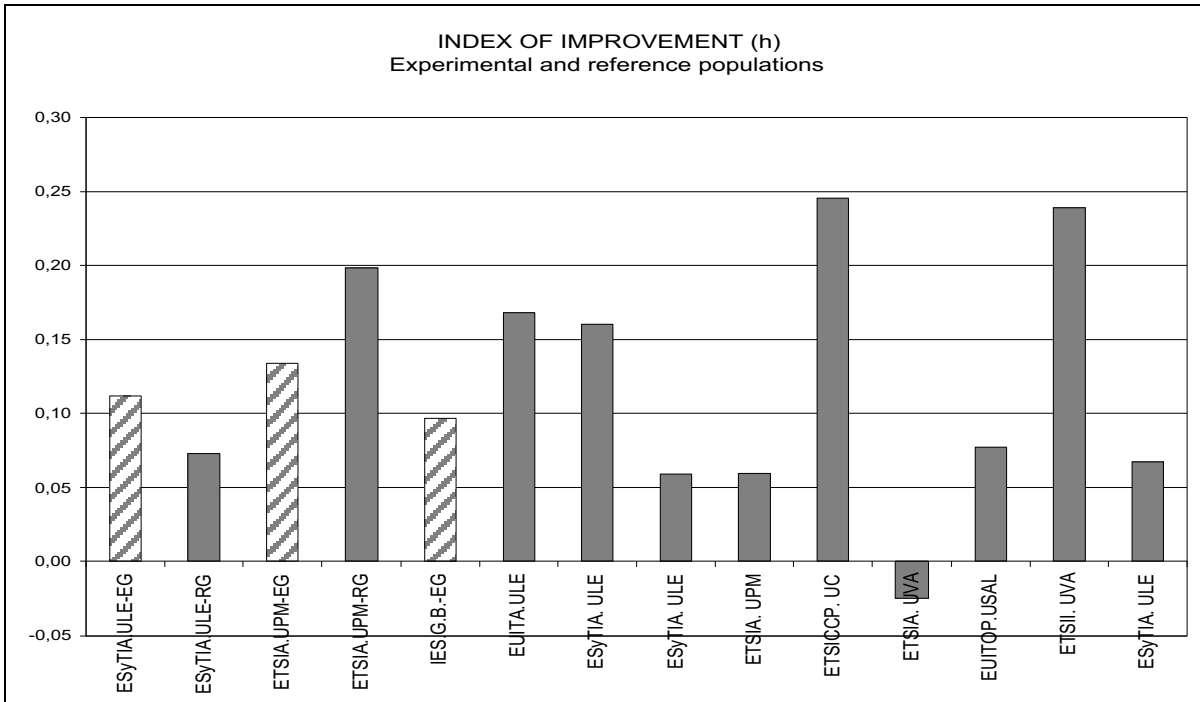


FIGURE 8

GLOBAL APPRAISAL OF THE EXPERIENCE BY THE STUDENTS

