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Improving Problem-Solving Skills using Adaptive On-line Training and Learning Environments*

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This study evaluates the effectiveness of an on-line adaptive training system aimed at improving students' abilities to solve physics problems. The system displays a set of multiple-choice problems along with the correct answer and several carefully designed distracters. The distracters correspond to typical mistakes that undergraduate students make according to the authors' teaching experience. Depending on students' choices, the system provides them with appropriate, timely feedback and prompts them to solve other problems to practise their problem-solving skills further. In this way students solve a different set of problems of different difficulty levels according to their particular learning needs. The system also has the capability of providing other didactic resources such as tutorials or virtual learning environments, such as active simulators, to enhance student learning. Owing to its flexible structure, the system allows for the sharing of test banks and didactic resources between different courses and professors. It also keeps track of student performance and generates specific reports. The software was tested using a sample of 169 undergraduate engineering students taking physics courses. Using a pre-test/post-test assessment tool, it is found that students using the software (the focus group) have a larger average integrated learning gain than students who did not use it (the control group). This conclusion is supported by a statistical analysis based on Z tests.

Keywords: engineering education; physics problem-solving; adaptive on-line training; learning gain.

1. INTRODUCTION

PROBLEM-SOLVING is one of the most common techniques used to assess students' comprehension of physical concepts and their ability to state and solve specific problems in Physics courses at different academic levels. In fact, typical Physics textbooks include a series of end of chapter exercises and problems so that students can practise their problem-solving skills (e.g. [1–3]). Nevertheless, when students try to solve a given problem they often face big difficulties because they lack a methodology to address it or they fail in the procedure to solve it. Furthermore, due to their tight schedules, professors are often not available to assist students properly when they encounter difficulties in problem-solving, and Teaching Assistants are not always the best option for this purpose. Therefore an on-line problem-solving training system available to students any time and anywhere is highly desirable to support student learning.

Nowadays, the use of on-line tools to assist teaching and learning of several engineering disciplines, including physics and maths, is becoming a common practice among professors teaching undergraduate courses in major universities worldwide (e.g. [4–6]). It is very common to find publications related to the use of web-based learning environments for assessing and training student work (e.g. [7–9]). In many cases significant student performance improvement is reported (e.g. [8–10]). Nevertheless, as pointed out by [11], it is important to mention that such systems by themselves do not contribute significantly to the learning process, and a good pedagogical framework is needed to develop truly effective student learning. Also an adaptive system is necessary that responds to individual student needs, in a progressive or scaffolded way according to student level and mastery of a given subject, in order to provide

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students with the best pedagogical assistance through their interaction with the system [8, 9].

In the case of Physics teaching, the so called *Companion Websites* included by textbooks sold by major publishers have become a handy tool both for teachers and students. Examples of these on-line tools include *MasteringPhysics* (Pearson) [12], *WileyPlus* (John Wiley & Sons Ltd) [13], *Connect* (McGraw-Hill) [14], *CengageNow* (Cengage) [15], and *WebAssign* (Advance Instructional Systems) [16]. These websites provide the professor and the student with large sets of specifically designed exercises and problems grouped either by discipline or textbook. They provide a helpful tool for the professor to build on-line quizzes, homework, and exams that are automatically graded by the system. These systems keep track of each student's performance and show the course statistics in different ways so that professors can study the behaviour of their groups. However, the feedback given to students when they make an error, either in physics or maths, is still too general and can be improved and focused according to the particular student's needs, taking into account their interaction history with the system.

With this aim in mind, the e-Learning Research Group at the *Tecnológico de Monterrey, Campus Ciudad de México* has developed an on-line training system aimed to help professors to define and manage appropriate sets of problems on the one hand, and to help students to use these problems to improve their knowledge and their problem-solving skills on the other. This system also allows the sharing of specific content between different professors and courses, and generates specific reports about student performance. This adaptive on-line system is named '*Aaprender*' and preliminary versions of it can be found in [17] and [18]. The main purpose of this work is to present the basic structure of *Aaprender* and how it was used to promote student problem-solving skills for undergraduate Physics courses.

The next section is devoted to the structure of *Aaprender* and how the information from a given course or subject is entered into the system. A case study applied to several undergraduate Physics courses is presented in Section 3. Section 4 describes the evaluation process, while Section 5 presents the results in terms of an Integrated Relative Learning Gain for students that used *Aaprender* and for students that did not use it (hereafter 'the focus group' and 'the control group', respectively). In the last section, the main conclusions of this study and future work are presented.

2. *AAPRENDER*: AN ON-LINE ADAPTIVE LEARNING AND TRAINING ENVIRONMENT

Aaprender is constructed based on previously defined modules for a given course (either for a Physics or a Maths course), linked through hierarchical nets to facilitate the internal navigation, and it aims to give timely adaptive feedback to each student according to his or her interaction with the system. The main features of *Aaprender* are as follows.

It is based on a pedagogical structure for a given course where the concepts are classified into an appropriate hierarchical scheme. This structure allows professors to incorporate and share diverse pedagogical resources (such as problems, exercises, simulators, videos and tutorials) between different modules of a given course or between different courses.

It provides adaptive feedback to students according to their particular mistakes.

It also provides additional practice problems in order to reinforce student problem-solving skills, where the complexity of the additional problems depends on the individual student's needs and student's history of interaction with the system

It provides adequate student performance reports for the professor. The structure of the system is flexible, adaptable and can be increased in order to suit additional pedagogical requirements.

Aaprender provides different services according to the user role. Each group of user (role) has different entry permissions that define the kind of functionality offered by the system. Figure 1 shows the main functions of the system that is allowed for the manager, for the head of department and for the professor role.

A manager is able to provide access to all other users: head of department, professors and students. The manager also sets the period of availability for the courses and can generate specific control reports. The head of department gives the professor permission to access the system, to

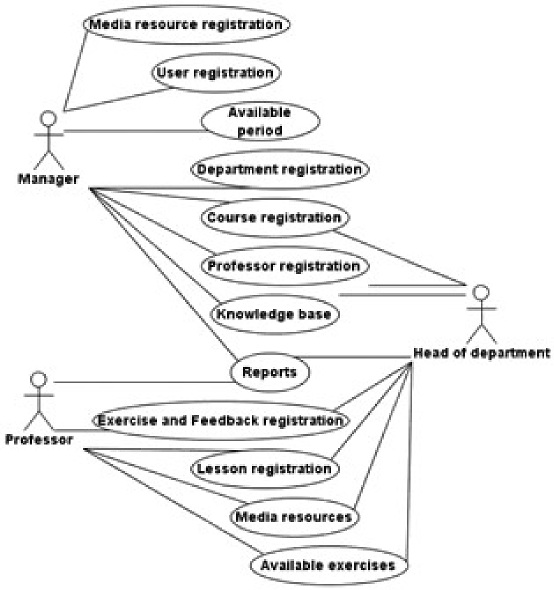


Fig. 1. Functional use cases of *Aaprender*.

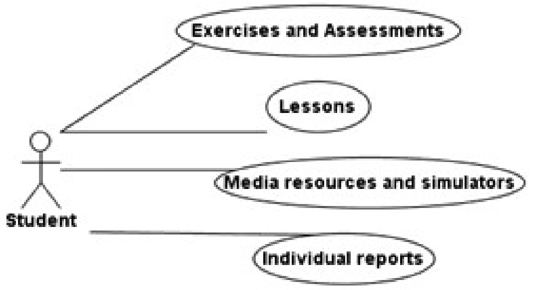


Fig. 2. Learner's use cases of *Aaprender*.

register the problem-knowledge base (see below), and to consult statistics and reports on the student performance. On the other hand, the professor registers the exercise problems by theme, difficulty level and period; defines the corresponding feedback for the student and the media resources related to an exercise; and obtains statistics and reports of his or her groups.

To use the system, the learner can choose to enter either a training area or an assessment area. Next, *Aaprender* displays the functionality shown in Fig. 2. Then the system shows the student the different content areas previously defined by the professor, and when he or she chooses a given module, the system displays a set of exercises previously defined for that module and period in a random order. The student can try to solve each exercise several times, and every time the system gives him or her appropriate feedback for this exercise and a personalized navigation path to continue solving problems from the given list.

Aaprender allows professors to create a bank of problems and didactic resources that can then be shared between different courses and solved online by students. The system architecture is based on SOA [19] as shown in Fig. 3. This architecture is aimed at providing a structure to manage exercises or problems according to a previously defined knowledge–course structure.

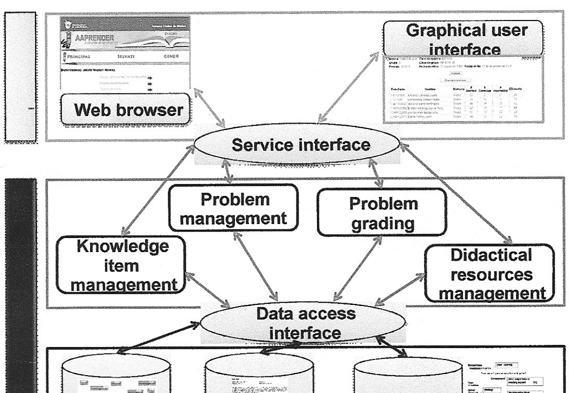


Fig. 3. *Aaprender* software architecture.

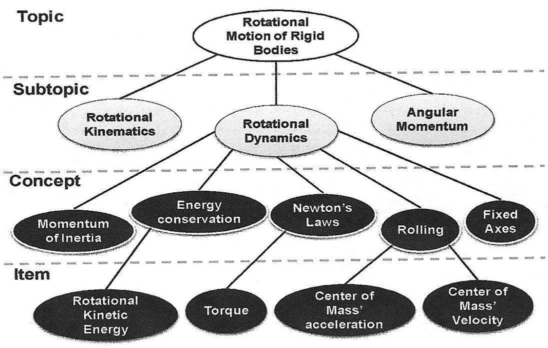


Fig. 4. Segment of the hierarchical graph for a Classical Mechanics course.

This system uses three databases: a knowledge-base, a problem-base and a didactic resource-base. In the knowledge-base, professors can define the knowledge structure of a course. This structure has a hierarchical graph organization that denotes the relationships between the main concepts that are taught in the course. For example, Fig. 4 shows a segment of the hierarchical graph for the Rotational Motion of Rigid Bodies module of a basic undergraduate Physics course at our institution.

The problem manager uses the knowledge-base, the problem-base, and the professor's selection to allow a categorization of each set of problems in three levels corresponding to their difficulty: High (H), Intermediate (I) and Low (L). These categories are used to give adaptive exercise navigation to the user depending on the student's results and interaction history with the system.

The students are prompted to solve an initial set of exercises (usually of level I) from the problem-base. Each problem may have some lower difficulty associated problems, each of them corresponding to one or several distracters for this particular initial problem. In this way students are guided to identify the origin of their mistakes in a simpler exercise. In some cases, when the student's answer is correct, the student is asked to solve a problem with a higher difficulty level in order to motivate students with new challenges. If the student solves the related problem successfully, the system displays the next exercise of the initial set. Figure 5 shows this adaptive navigation.

The didactic resources database is used to store didactic tools that will help students in their learning process. Using a didactic resources management module a professor can store a set of didactic resources such as Java Virtual Laboratories, Flash simulators, videos, tutorials or other learning environments. For each element of this type, the professor can define the set of variables that can be explored within the experiment. These didactic resources can then be linked to a problem to enrich the student learning process. The didactic resources can also be shared between all the professors with access to the system in order to be used in their specific courses.

The tutorial didactic resources define basic

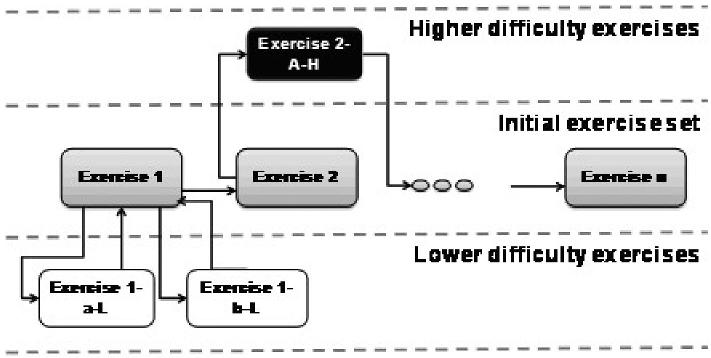


Fig. 5. Adaptive exercise navigation.

concepts needed to understand a phenomenon included in a problem statement. They can also include complementary explanations or examples to reinforce what has been taught in the classroom. For each lesson, a professor must define the node in the course knowledge-base that is addressed by the tutorial. The main objective for this organization is to map tutorials directly to the problems (and vice versa) so that students and professors can easily find these resources attached to the course structure.

Once a problem or a didactic resource is defined in the system, professors can assign them to their groups. When professors select a group from their course list, the system displays all the problems and resources that are available for that course. Because the problems are defined in a common database, this listing contains all problems attached to the knowledge structure base of the course that have previously been defined by professors with access to the system. From this list, professors can select those problems to be solved by the students and those resources that may also be accessed by them. This process can be repeated for all the courses to which a professor has access.

After this process is done, registered students can log into the system to select a course within the list of courses in which they are enrolled. They will then have access to the problems selected by the professor for that course or course module. When students click the 'Answer' button, the system displays the selected problem statement. The problem view is divided into three parts. The first part contains the problem general information. The second part displays the problem statement and the associated image. The last part encloses the right answer, four distracters, and a button to submit the student's selection. These five choices are displayed in a random order each time a student requests this page so as to avoid simple memorization or copying among students.

When students click the 'Grade' button, the system grades the problem by comparing the answer given by the student and the correct answer indicated by the professor. Then, the system stores the attempt and navigation path information needed to create reports both for the student and the professor. Finally, the system displays the feedback associated with the selected answer. If there is a didactic resource associated with the problem, the simulation, video, tutorial, or learning environment is displayed. The students can then practise with the didactic resource with the aim of better understanding the phenomenon implicit in the problem. After working with the didactic resource, the student can try to solve the original problem again.

In order to be able to give surveillance to the student learning process, the system can provide the professors with three different kinds of reports about the student's interactions within the system: a student report, a problem report and an answer report. All these reports can be generated for a specific period of time and can be downloaded whenever necessary. In the next section, a case study for a Physics course is described.

3. CASE STUDY: *AAPRENDER* APPLIED TO A PHYSICS COURSE

The first step in this study was to define the knowledge course structure, that is, the modules and sub-modules of the undergraduate Physics I course (Classical Mechanics) for Engineering students at our institution. The main modules for this course are: I. Vectors and basic concepts; II. Kinematics; III. Particle Dynamics; IV. Work and Energy; V. Systems of Particles; VI. Rotational Motion of Rigid Bodies and VII. Equilibrium. So far, attention has been focused on Modules III and VI, which contain the central topics of the course. For these two modules, a knowledge item graph including the main themes, sub-themes, concepts and specific knowledge items of the module was defined, as well as the main associations among these concepts. The corresponding knowledge item graph for Module VI was shown in Fig. 4. These graphs will serve as a guide to selecting adequate problems for the students.

In order to feed the on-line training system, a set of problems for Modules III and VI was carefully selected. For Module III, these problems cover the themes of Linear Dynamics without Friction, Linear Dynamics with Friction, and Circular

Dynamics; while for Module VI, the problems cover the themes of Torque, Moment of Inertia, Rigid Body Rotation around a Fixed Axis, and Rolling. The problems have a structure and level similar to those of typical problems included in most Physics textbooks for scientists and engineers (e.g. [1–3]).

As explained in the previous section, when students first enter *Aaprender*, choose a group and then a Module, the system displays a list of initial problems previously selected by the professor for that module of the course. These 'initial problems' have the same difficulty level as those assigned for homework or monthly tests by the teacher and cover the main topics of the module. Each initial problem has five possible answers: the correct answer and four *distracters* carefully designed so as to match the most common mistakes that students have for these kinds of problems. This selection of distracters is supported by the authors' teaching experience of more than 20 years working with engineering students. So, for each distracter, a specific associated feedback has been defined. This feedback will be used by the system in order to help students identify the source of their mistakes. A preliminary discussion on the criteria followed for designing the distracters is presented in [20].

As stated in the previous section, the feedback for each distracter consists of a simple question, statement or hint aimed to help students to find out the source of their mistake. In some cases, students are also prompted to solve an associated sub-problem designed to reinforce those specific misconceptions or mistakes associated with the distracter. In this way, an initial problem may have several associated 'sub-problems', each of them corresponding to one or several distracters for this particular initial problem. In most cases, the sub-problem level difficulty is lower than that of its initial problem for the students to identify the origin of their mistakes in a simpler exercise. Once students have solved the sub-problem, they are asked to try to solve the initial problem again. Note that not all the initial problems necessarily have associated sub-problems. In fact, for the simplest initial problems, the hint or feedback given by the system should be enough for students to find the source of their mistake. However, in some cases, when the student's answer is correct, he or she is asked to solve a problem with a higher difficulty level so as to keep them motivated, as mentioned before.

Each sub-problem may also have up to five possible answers, each one with its corresponding specific feedback. Once the student finds the right answer for the sub-problem, he or she is prompted to go back to solve the original problem. If the answer for the original problem is correct, the student is then asked to solve the following problem of the problem list of the module. In this way, for a given module, all students should solve all the initial problems of the list, but only a subset of the

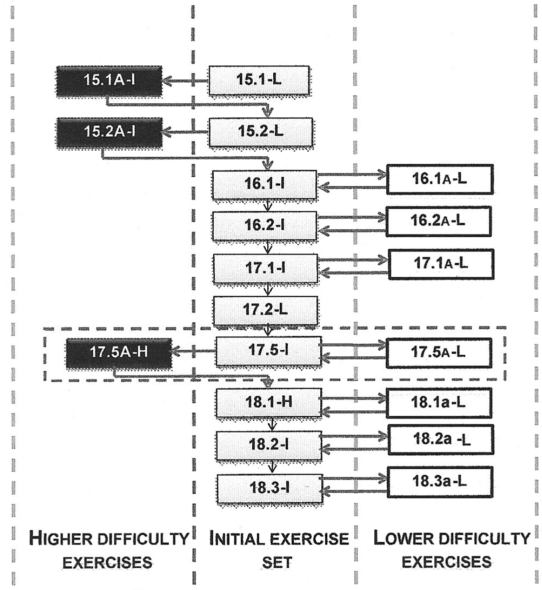


Fig. 6. Navigation Map for problems and their associated sub-problems for the Rotational Motion of Rigid Bodies module.

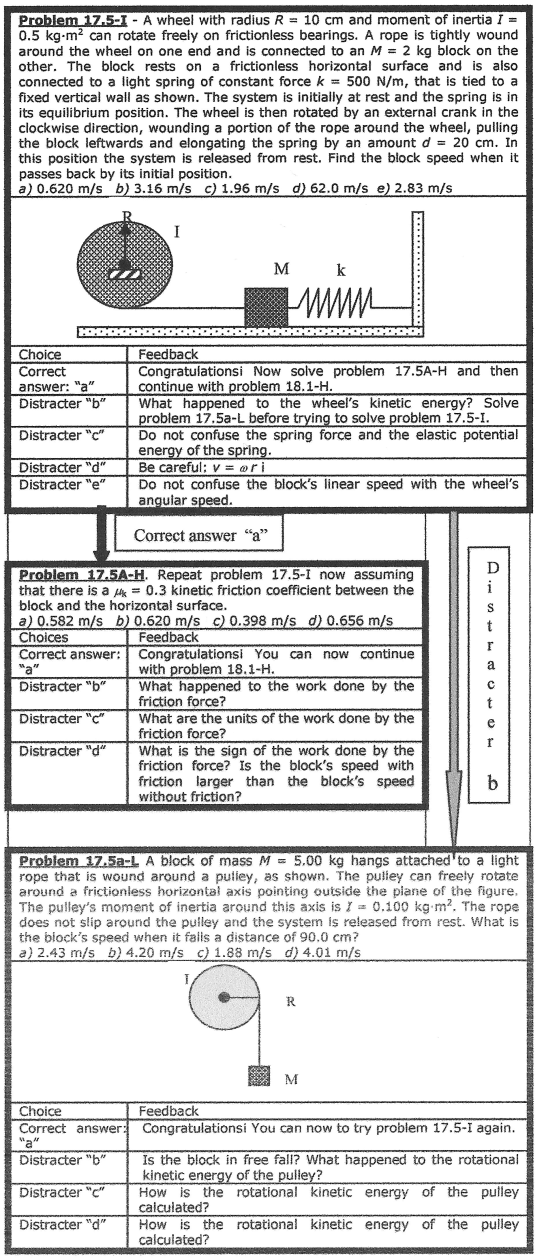
module sub-problems, depending on the selected distracters. In this sense, each student will have his or her own navigation path and feedback within the problem list, providing a personalized guide to develop his or her problem-solving skills and helping students to understand the origin of their mistakes and particular misconceptions. This also enhances and motivates student self-learning, a practice that is highly desirable for the students.

To illustrate better how the system works, the current navigation map for problems of Module VI is shown in Fig. 6. A similar map was designed for Module III. The initial problems are presented in the middle column and their associated higher and lower difficulty sub-problems are shown in the left and right-hand columns, respectively. As mentioned before, the difficulty level of each problem is indicated by the final character (H = High, I = Intermediate, L = Low). The concepts related to each particular problem of Module VI are given in Table 1.

As an example of the navigation within the system, the relation between Problems 17.5-I, 17.5A-H and 17.5a-L is shown in Fig. 6 (see the dashed box). Their statements, correct answers, distracters, feedbacks and instructions to be followed by students are presented in Fig. 7.

Table 1. Relation between problems and their concepts for the Rotational Motion of Rigid Bodies module.

Problems	**Concept**
15.1-L, 15.1A-I, 15.2-L, 15.2A-I	Rotational kinematics
16.1-I, 16.1a-L, 16.2-I, 16.2a-L	Torque
17.1-I, 17.1a-L, 17.2-L	Moment of inertia
17.5A-H, 17.5-I, 17.5a-L	Fixed axis
18.1-H, 18.1a-L, 18.2-I, 18.2a-I, 18.3-I, 18.3a-L	Rolling



Problem 17.5-I - A wheel with radius R = 10 cm and moment of inertia I = 0.5 kg·m^2 can rotate freely on frictionless bearings. A rope is tightly wound around the wheel on one end and is connected to an M = 2 kg block on the other. The block rests on a frictionless horizontal surface and is also connected to a light spring of constant force k = 500 N/m, that is tied to a fixed vertical wall as shown. The system is initially at rest and the spring is in its equilibrium position. The wheel is then rotated by an external crank in the clockwise direction, wounding a portion of the rope around the wheel, pulling the block leftwards and elongating the spring by an amount d = 20 cm. In this position the system is released from rest. Find the block speed when it passes back by its initial position.
a) 0.620 m/s *b)* 3.16 m/s *c)* 1.96 m/s *d)* 62.0 m/s *e)* 2.83 m/s

Choice	Feedback
Correct answer: "a"	Congratulationsi Now solve problem 17.5A-H and then continue with problem 18.1-H.
Distracter "b"	What happened to the wheel's kinetic energy? Solve problem 17.5a-L before trying to solve problem 17.5-I.
Distracter "c"	Do not confuse the spring force and the elastic potential energy of the spring.
Distracter "d"	Be careful: $v = \omega r$ i
Distracter "e"	Do not confuse the block's linear speed with the wheel's angular speed.

Problem 17.5A-H. Repeat problem 17.5-I now assuming that there is a μ_k = 0.3 kinetic friction coefficient between the block and the horizontal surface.
a) 0.582 m/s *b)* 0.620 m/s *c)* 0.398 m/s *d)* 0.656 m/s

Choices	Feedback
Correct answer: "a"	Congratulationsi You can now continue with problem 18.1-H.
Distracter "b"	What happened to the work done by the friction force?
Distracter "c"	What are the units of the work done by the friction force?
Distracter "d"	What is the sign of the work done by the friction force? Is the block's speed with friction larger than the block's speed without friction?

Problem 17.5a-L A block of mass M = 5.00 kg hangs attached to a light rope that is wound around a pulley, as shown. The pulley can freely rotate around a frictionless horizontal axis pointing outside the plane of the figure. The pulley's moment of inertia around this axis is I = 0.100 kg·m^2. The rope does not slip around the pulley and the system is released from rest. What is the block's speed when it falls a distance of 90.0 cm?
a) 2.43 m/s *b)* 4.20 m/s *c)* 1.88 m/s *d)* 4.01 m/s

Choice	Feedback
Correct answer: "a"	Congratulationsi You can now to try problem 17.5-I again.
Distracter "b"	Is the block in free fall? What happened to the rotational kinetic energy of the pulley?
Distracter "c"	How is the rotational kinetic energy of the pulley calculated?
Distracter "d"	How is the rotational kinetic energy of the pulley calculated?

Fig. 7. Problem 17.5-I and associated sub-problems 17.5A-H and 17.5a-L.

There are five choices when solving the initial problem 17.5-I:

(i) If students select the correct answer (choice 'a'), they are congratulated and prompted to solve the higher difficulty level problem 17.5A-H. This problem has been specifically designed for students to understand the role of including frictional forces in problem 17.5-I. Problem 17.5A-H also has several options with their corresponding feedback. Students are prompted to solve this problem correctly before continuing with the next problem on the list, that is, Problem 18.1-H.

(ii) If students select choice 'b', the system provides appropriate feedback for this distracter (not including kinetic rotational energy), and they are asked to solve the lower difficulty level sub-problem 17.5a-L before going back to try problem 17.5-I again. In this case, Problem 17.5a-L has been specifically designed for students to review the concept of kinetic rotational energy in a simpler case than that of Problem 17.5-I. Note that sub-problem 17.5a-L also has several options along with corresponding feedback.

(iii) If students select answers 'c', 'd' or 'e', the system gives them feedback to help them find the origin of their mistake and then prompts them to try to solve problem 17.5-I again. There are no sub-problems for these three distracters.

In this way, students are asked to complete the cycle included in each problem or sub-problem until all of the problems are solved correctly. Once this is accomplished, students are asked to continue with the next problem on the original list. In this way, students practise with several problems of different level difficulties and strengthen their problem-solving skills and self-learning.

4. EVALUATION PROCESS

In order to evaluate the impact of *Aaprender* on developing students' problem-solving skills, engineering students enrolled in four Physics I classes at the Tecnológico de Monterrey, Campus Ciudad de México in the August–December 2008 and the January–May 2009 terms were chosen. These classes were taught by two different professors (two of the authors), each one in charge of two classes. The total student sample was divided in two groups: a *focus group,* which was given access to the software (N_{FOCUS} = 64 students) and a *control group* which *did not* use the software ($N_{CONTROL}$ = 105 students); giving a total sample of N = 169 students. Students were distributed in these two groups according to their current grades in order to have an equal distribution of ability levels in both groups. Also, care was taken to have the same proportion in both the focus and control groups of students from each class and each professor. *Aaprender* was applied in three runs, one in the August–December 2008 term and two in the January–May 2009 term. The actual student populations that participated in each run are shown in Table 2.

In all runs, a pre-test and a post-test were applied to both the focus and the control groups in order to compare results for these two samples. The pre-test and the post-test were similar; both in the problem structure as well as the level of difficulty. Pre-test and post-test problems had a difficulty level very similar to that of problems included in *Aaprender* and typical problems included at the end of chapters of most textbooks

Table 2. Dates and number of students who participated in the three runs of *Aaprender*

Run	Term	N_{FOCUS}	$N_{CONTROL}$
A	Aug–Dec 2008	31	35
B	Jan–May 2009	20	38
C	Jan–May 2009	13	33
Total (All)		64	105

for engineering undergraduate students (e.g. [1–3]). The pre-test and post-test were designed to measure the student's abilities to solve problems in the sense that, in order find the right answer, the student needs to understand the problem, to state it, and to carry out the corresponding mathematical operations to solve for the unknowns.

The pre-test and post-test contained three multiple choice Physics problems with five options each. Both tests were applied in the classroom and all the students (both focus and control) were given approximately 20 minutes to complete each test. In order to preserve data uniformity, all tests for all runs were graded by the same professor following the same convention for grading each problem. The scale for test grades was normalized to 100 points.

Care was taken to have as similar as possible initial and final test conditions for the control and focus students. The pre-test was applied to all students, before the professor started discussing the corresponding themes in the class. After this, the focus group was allowed to have access to the *Aaprender* system and was given specific instructions to practise for the next two weeks. Meanwhile, the professor continued with his lecturing in both the focus and the control groups. After this period, the post-test was applied to both groups. The students of the focus group were able to enter *Aaprender* as many times as they wanted to within the allowed two-week period, while control students were asked to practise similar problems on paper for the same period of time. No minimum practice time was required for any student sample. The average number of accesses to *Aaprender* per focus student in this two-week period was about 10; with some students accessing the system more than 20 times. Indeed, it is interesting to note that many focus students felt very motivated to dedicate extra time to practise with the software, which indicates that the use of the system encouraged them to spend more time studying compared with the control students.

5. RESULTS AND DISCUSSION

5.1 Student Individual Relative Gains

In order to analyse the results of this study, the student individual relative gains were first calculated, in a similar way as [21]:

Relative gain for student '*i*':

$$g_i = \frac{Post_i - Pre_i}{100 - Pre_i} \qquad (1)$$

where Pre_i and $Post_i$ are the pre-test and the post-test grades respectively obtained by student '*i*'. Student individual relative gains, g_i, for all students included in this study are plotted in Fig. 8 in two separate sequences: one for focus students (heavy diamonds) and the other for control

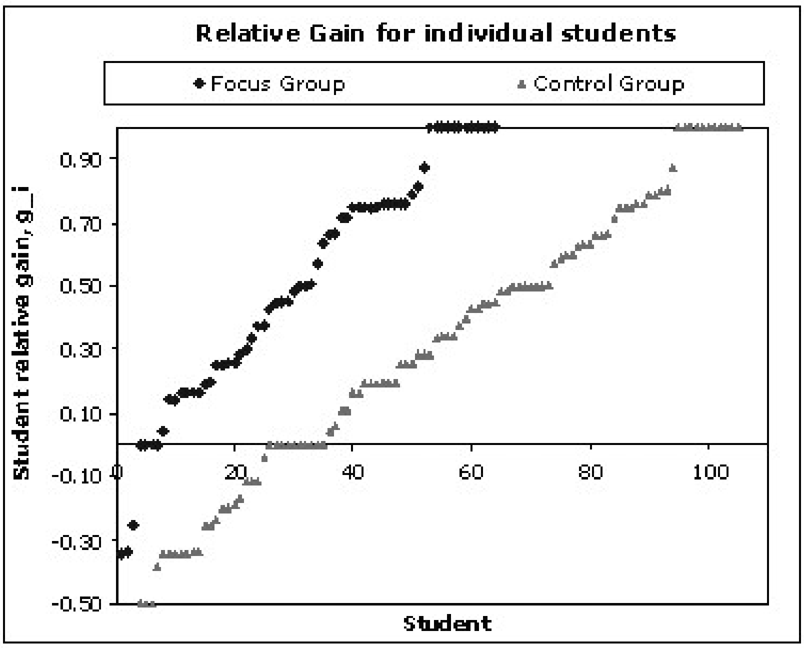


Fig. 8. Relative gains for students, g_i, for the focus group (diamonds) and for the control group (triangles). Both sequences are ordered by increasing gain

students (light triangles). For clarity, the sequences are superimposed and ordered by increasing gain. Note that focus students have a larger proportion of positive gains than control students.

5.2 Average Pre-test, Post-test and Relative Gains

In order to compare the gains in more detail for focus and control students, average pre-test grades, average post-test grades, and average relative gains were also calculated. These quantities are defined as follows, where N is the number of students for a given run or sample:

Average pre-test grade for a given sample:

$$< Pre >= \frac{\Sigma_i \; Pre_i}{N} \tag{2}$$

Average post-test grade for a given sample:

$$< Post >= \frac{\Sigma_i \; Post_i}{N} \tag{3}$$

Average relative gain for a given sample:

$$< g_i >= \frac{\Sigma_i \; g_i}{N} \tag{4}$$

Being similar in nature and procedures, we grouped the samples of the three runs to comprise a larger sample. Our results are summarized in Table 3, where we show the total focus and control populations together with their corresponding average pre-test, post-test and relative gains. The corresponding standard deviations are also included.

As shown in Table 3, the average pre-test grade, $<Pre>$, is very similar for the focus and control groups, indicating the fact that the initial problem-solving skills of the students prior to the use of the software are similar for both groups, as expected (36 and 37, respectively). However, the average post-test grade, $<Post>$, is larger for the focus group than for the control group (69 vs. 57, respectively), which indicates that focus students obtained better learning gains than control students. Owing to the rather large standard deviations and in order to test this last hypothesis, a statistical Z test was applied to check whether the difference of these two averages is significant (e.g. [22]). It was found that, with 95% confidence, the difference ($<Pre>_{\mathrm{FOCUS}} - <Pre>_{\mathrm{CONTROL}}$) is not significant, but the difference ($<Post>_{\mathrm{FOCUS}} - <Post>_{\mathrm{CONTROL}}$) *is* significant and it lies in the interval [4.43, 19.6]. This result shows that the average post-test grade for focus group is statistically larger than that obtained for the control group.

Table 3 also shows that the average relative gain is larger for focus students, $<g_i>_{\mathrm{FOCUS}}$, than for control students, $<g_i>_{\mathrm{CONTROL}}$. As before, a Z test with these data was carried out, and it was found that the difference between the two average relative gains is also significant, with a 95% confidence, and lies in the interval [0.112, 0.387], indicating that the average relative gain for the focus group is statistically larger than for the control group.

Table 3. Average and standard deviation of pre-test, post-test and relative gains for the focus and control groups

Group	***N***	$<Pre>$	$<Post>$	$<g_i>$
Focus	64	36 ± 18	69 ± 24	0.51 ± 0.37
Control	105	37 ± 18	57 ± 25	0.26 ± 0.54

5.3 Integrated Relative Gains

In addition to students' relative gains, we have also calculated an 'integrated' relative gain, G, for each run (A, B and C), and also for the total sample, both for the focus and control groups, as defined by [21]:

Integrated relative gain for a given sample:

$$G = \frac{< Post > - < Pre >}{100 - < Pre >} \tag{5}$$

The results for the focus and control groups are shown in Tables 4 and 5, respectively. In a similar way as [21], a plot of the integrated relative gains vs. the average pre-test for each run (A, B and C) and the total sample is shown in Fig. 9. The integrated relative gains for focus students are plotted as filled symbols, while for control students they are plotted as empty symbols. It is clear from Fig. 9 that the integrated average gain is larger for focus groups than for control groups for each of the three runs as well as for the entire student sample. This result is consistent with the Z tests discussed above, as expected. In fact, for the entire student sample it is found that $G_{\mathrm{FOCUS}} = 0.51$ while $G_{\mathrm{CONTROL}} = 0.32$ (see Tables 4 and 5).

The results of this study show that focus students obtained larger learning gains than control students, suggesting that the use of *Aaprender* improves student's problem-solving skills and promotes an improvement in students' understanding and knowledge, as measured by the results obtained with the pre- and post-tests.

It is worth mentioning two important points:

(i) Two additional professors at Tecnológico de Monterrey also used the software in the August–December 2009 term in an Introductory Physics class, and preliminary results are also consistent with the assertion that focus students obtain larger learning gains than control ones (work in progress).

(ii) A very important upgrade of *Aaprender* is planned to include dynamic algorithmic-generated problem suites, a preliminary version of which is described in [23]. In this case, numerical values of variables in a given problem will change every time a student enters the system in order to minimize simple memorization of results. In addition, no choices will be shown to students so they will have to enter the result using a specific format in an empty field for this purpose.

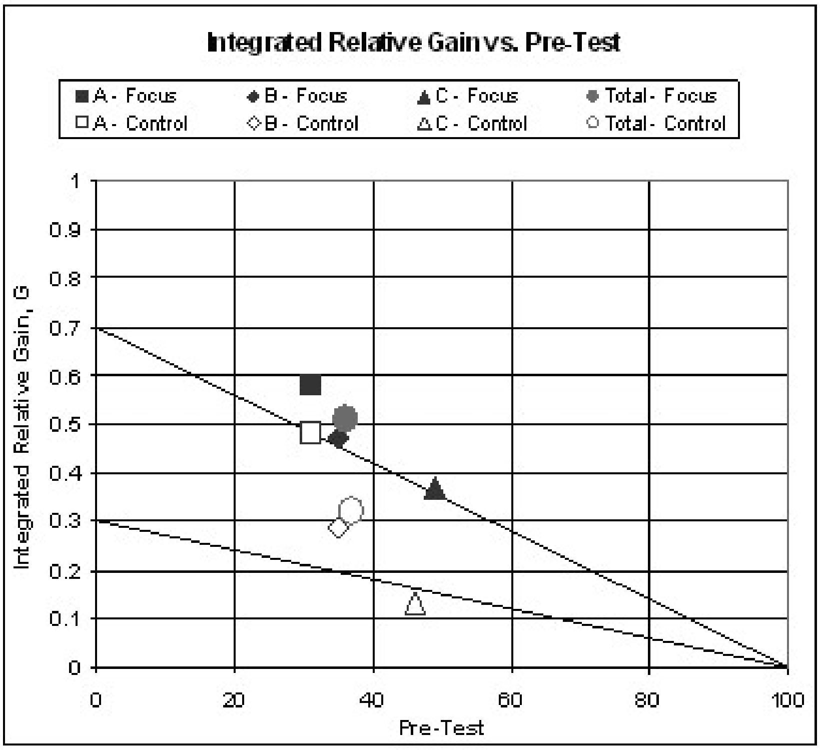


Fig. 9. Integrated relative gain vs. average Pretest for runs A (squares), B (diamonds), C (triangles) and for the total student sample (circles). Filled and empty symbols indicate focus and control groups, respectively

Table 4. Integrated relative gains for the three different runs A, B and C, and for the total number of students for the focus group

Run (Focus)	*N*	<*Pre*>	<*Post*>	G
A	31	31	71	0.58
B	20	35	66	0.47
C	13	49	68	0.37
Total (All)	64	36	69	0.51

Table 5. Integrated relative gains for the three different runs A, B and C, and for the total number of students for the control group

Run (Control)	*N*	< *Pre* >	< *Pos* >	*G*
A	35	31	64	0.48
B	37	35	54	0.29
C	33	46	53	0.13
Total (All)	105	37	57	0.32

6. CONCLUSIONS AND FUTURE WORK

Practising problem solving is a key factor in engineering education. *Aaprender,* an On-line Learning Environment, gives students the opportunity to gain self-confidence before performing formal assessment tasks. The system gives proper feedback to the students so to encourage them to continue their learning by solving exercises. The selected problems, appropriate distracters, and tutorial actions related to feedback were carefully designed. Each student is presented with a different navigation path within the system and will solve a different set of problems for a given module, according to his or her individual learning needs, so student self-learning is promoted.

As an on-line training tool, these conclusions support the idea that the system gives the student more productive time on task. In fact, students were so motivated by the system that they felt more engaged in solving problems than those students that did not use it. This is because present-day student generations are more familiar with electronic media than previous generations. That is why a system like *Aaprender* can be very helpful to promote student self-learning. Students were also motivated by the richer problem environment made possible by a computer-based system that includes tutorials and active learning simulators. Further research and development work is in progress to create richer on-line training environments to support the learning and teaching process.

The results that have been derived from the case study encourage the authors of this work to increase the problem-base for each course module and the didactic resources-base of the system. In particular, more visual resources should be added (simulators, videos, etc . . .) to reinforce student learning. Owing to its flexibility and capabilities, *Aaprender* can also be used for other engineering disciplines such as Mathematics and Computer Science. A set of problems, appropriate distracters and tutorial actions to use

'*Aaprender*' in some Mathematics and Computer Science courses are being developed.

From an educational point of view, it was found that: (a) the pre-test/post-test assessment tool used allows us to test the usefulness of the system; (b) the results obtained from a sample of 169 undergraduate Physics students point in the right direction: students who used the system obtained a larger integrated average learning gain than those who did not use it; (c) adequate students' performance reports for the teacher were provided. Also, the didactic resources associated with the problems reinforced the student learning process according to the pedagogical objectives required by the course.

On the other hand, from a technological point of view, the system advantages are: (a) it allows for the creation of test banks and didactic resources of different kinds (videos, Flash simulations, Java learning environments) to be shared by different professors and/or courses; (b) it offers the student on-line access to these resources; (c) it provides timely feedback to students, and (d) it is available on-line so it can be accessed any time, anywhere.

The future related research projects include:

(i) Carrying out a detailed analysis of the distribution of the distracters' occurrence. This will lead to improvement of both the problems design strategy, their multiple choice options (including the distracters) and the corresponding feedback given to the student.
(ii) Developing an upgraded version of *Aaprender* that includes dynamic algorithmic-generated problem suites, where numerical values of variables in a given problem will change every time a student accesses the system. This will minimize copying between students and memorization of fixed results.
(iii) Integrating *Aaprender* with mobile devices (m-Learning) so students and professors can benefit from data access to the system resources from a remote place.
(iv) To increase and strengthen the didactic resource-base.
(v) Creating a set of authoring tools in order to help professors construct an instructional graph that will define the sequence of problems to be solved by the student. These authoring tools will themselves benefit from the course hierarchical graph representation in order to help in the creation of domain models and student models that are aimed for the construction of an Intelligent Tutoring Systems associated with the didactic resources.

Access to *Aaprender* for a Physics course is available at: http://elearning.ccm.itesm.mx:8080/Aaprender (please contact jnoguez@itesm.mx).

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