Active learning of physics: Synergy of teaching strategies

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(Received 12 September 2011; accepted 15 January 2012)

Abstract

We report on the application of Tutorial for Introductory Physics and Interactive Lecture Demonstrations (ILD's) in the Mechanics course taken by engineering students at the Universidad Nacional de San Juan. Argentina. A pre/post test quasi experimental design was implemented to compare the learning gains of two previously formed complete groups of engineering students. One of the groups continued with the traditional instruction, while in the experimental group active learning strategies were introduced in two steps: the first experiment included only Tutorials, while in the second experiment ILD's were added. Conceptual knowledge was measured with the Force Concept Inventory (FCI) test, while the institutional evaluation included three rather traditional problem solving written exams. A normalized gain of g=0.27 was obtained in the control course, well above the average for traditional instruction, as indicated by the wide study of Hake. The experimental instruction yielded g=0.56 in the first application and g=0.62 in the second experiment, indicating the synergy of using together coherent teaching strategies. The most striking result is the high degree of student success in the institutional evaluation, which increased the fraction of retained (successful) student to more than double that obtained by the traditional instruction. Implications for educational reform in similar educational systems are discussed.

Keywords: Active learning, Tutorials, FCI, mechanics.

Resumen

Como ejemplo de aplicación de las metodologías de aprendizaje activo en cursos de física básica para carreras de ingeniería se describen dos experimentos sucesivos. En el primero, se implementó la estrategia "Tutoriales para Física Introductoria" y se la comparó con un curso donde se siguió practicando la enseñanza tradicional, mientras que en la segunda experiencia se incorporaron a los Tutoriales algunas clases estructuradas de acuerdo a la estrategia "Clases Interactivas Demostrativas" (CID). Estas experiencias fueron realizadas en los cursos normales de Física Básica para estudiantes de ingeniería de la Universidad Nacional de San Juan (Argentina). Se utilizó un diseño de comparación de grupos preestablecidos, con determinación del conocimiento pre y post instrucción mediante el test Force Concept Inventory. Los cursos con estrategias de aprendizaje activo lograron niveles de aprendizaje muy satisfactorios, distribuidos en la mayoría de los estudiantes de la muestra y obteniendo, en promedio, ganancias intrínsecas de g=0.56 en la primera experiencia y g=0.62 en la segunda experiencia, mientras que el curso testigo, con enseñanza tradicional, se obtuvo g=0.27. Estos resultados pueden considerarse típicos de la importante mejoría que puede lograrse en los aprendizajes utilizando estrategias de aprendizaje activo de la física de una manera coherente.

Palabras clave: Aprendizaje activo, Tutoriales, FCI, mecánica.

PACS: 01.40.gb-, 01.40.Fk, 45.20.D–. **ISSN 1870-9095**

I. INTRODUCTION

National evaluations and international surveys like PISA 2003, 2006 and 2009 [1] systematically show that the understanding of basic science and mathematics held by high school students of the different Latin American countries is extremely low, with the performance of students from leading countries in scientific development, like Brazil, Argentina and México in the bottom of the scale. Other studies show that only a small fraction of the student entering the universities succeed in finishing their programs, with cases like Argentina where only about 10-15% graduates, usually with long delays.

The School of Engineering of the National University of San Juan (Argentina) is no exception and different studies show the very low performance of their incoming students in conceptual and procedural surveys [2, 3]. This poor performance has been point out in national university evaluations as one area of institutional weakness, central obstacle to university development. This peer evaluation pointed out that the high degree of student drop out rate, and low academic performance (low fraction of passing grades, with the corresponding delay in student's studies, particularly in the first year of their engineering programs) were weak points that should be urgently addressed [4]. Upon that situation different studies call for changes in the teaching of basic sciences, and physics in particular [5, 6], to collaborate in solving these low levels of learning and achievement. In this framework and knowing about the potentiality of active learning methodologies in fostering higher student involvement and learning, within the AECID Project (C/018053/08) "Pedagogical actions to improve de scientific learning of students entering Iberoamerican universities" it was decided to carried out, as a pedagogical experiment, teaching kinematics and Newton's Law using two active learning teaching methodologies.

II. FRAMEWORK

Many studies have confirmed in very different courses and school systems that basic conceptual learning of physics is not the result of (traditional) instruction. Traditional teaching assumes essentially that the student by repetition will learn the different themes of the curriculum and will form with them the knowledge structure of the discipline. In this teaching approximation the instruction is generally deductive, with the teacher irradiating knowledge, and the student accepting and assimilating it, with a passive attitude. In this way the traditional inst ruction is poorly adaptive, usually not considering student's reflection about the world description given by the professor. It is paradigmatic that, although this teaching approach is instructor-centered, it is the student who is cognitively overloaded, since he/she is supposed to make explicit the implicit structure of the discourse of the professor. Students are also supposed to reflect about what they believe and what the professor explains, find the differences, confront and resolve them, without an explicit help or input from the teacher, unless until the time of (usually summative) evaluations. Traditional teaching is generally based on numerical problem solving, using characteristic end-of- the chapter exercises, and recipe-type laboratories. Educational research has shown, time and again, that these two potentially important activities produce no noticeable conceptual change in most students [7]. Research in physics education have also shown, in different populations and educational levels, that research-based curriculum are much more effective than traditional instruction in producing significative changes in the conceptual knowledge of basic physics. Profiting from the extensive research on alternative conceptions of the 80´s, the Physics Education Research (PER) community holds nowadays a great deal of knowledge about characteristics learning difficulties, which has been applied to develop very successful curriculum, specially in the last 15 years. The main idea here is that students held alternative conceptions that the instruction should help to change. It should also be considered that students, as any other human being, can only maintain their attention for a few minutes. Therefore lecture-based, active-learning methodologies propose activities to keep the student constantly engaged in the learning process. These methodologies also profit from the enormous influence that peer´s discussion can have on student's comprehension and qualitative learning [8, 9, 10].

Under this framework, the aim of this work is to analyze how the use of two of these active learning teaching methodologies, Tutorials for Introductory Physics [11] and Interactive Lecture Demonstrations [12], contribute to student understanding and performance on the initial subjects of the engineering physics curriculum, Kinematics and Newton's laws.

III. METHODOLOGY

This work consists of a comparison of already established groups. The control and experimental groups correspond to two classes or divisions of first year engineering students taking the first physics course (classical mechanics), corresponding one of three courses of the second semester of their engineering programs. The two groups share the same curriculum, teaching conditions (labs, teaching time, exams, etc.) and prior requisites (taking a calculus course in their first semester). The experiment was carried out in two consecutive years. In the first year the control group was compared with the experimental group where five Tutorials on Kinematics and Newton's Laws were implemented. In the second year Interactive Lecture Demonstrations (ILD's) on the same subjects were added to the teaching in the experimental group. Pre and Post test using the Force Concept Inventory (FCI) [13] test were given in all cases. All groups have between 60 and 70 students at the beginning of instruction.

In the first experience five Tutorials were implemented, while in the second experiment four ILD's on Kinematics and Dynamics were added to supplement the Tutorials instruction. Teaching also included some lectures, problem solving sessions and laboratory work. Since instruction had to be carried out under the same conditions in all divisions (university regulations on that subject are mandatory), total lecture and some recitation time was reduced in the experimental section to allow time for Tutorials. The Control group continued with the same traditional methodology followed up to now. It consisted of expositive lectures, recitation sessions where students practiced problem solving and laboratory work. Institutional evaluation consisted of three exams during instructions and a final exam, which must be given after the instruction is finished, in a period determined by the authorities. Exams consisted mainly of solving end-of-chapter type of problems. They were common to all divisions, and were decided by the professors of the other divisions. The following table describes the student samples:

TABLE I. Characteristics of experimental and control groups.

General	Control (N=25)	Experimental 2008 (N=55)	Experimental 2010 (N= 48)
Engineering Program	Chemical and Food Engineering	Electronics (ELO 2008)	Electronics (ELO 2010))
Teaching Strategy	Traditional	Tutorials	Tutorials + ILD's

Conceptual learning was measured in all cases using the multiple choice test Force Concept Inventory (FCI) [13] at the beginning of the course and after instruction of Newton's Laws had taken place, which corresponded to the time of the first partial exam.

IV. RESULTS AND DISCUSSIONS

A. Effect of Tutorials

In the first experiment lecture and recitation time was reduced in the experimental group to allow the use of five Tutorials: Acceleration in One Dimension, Representations of Motion, Forces, 2nd and 3rd Newton's Laws and Tension. Only the Tutorial on Representations of Motion involved laboratory work, while the others were paper and pencil work. However all of them were run in the Laboratory room, because its tables were more convenient for the collaborative small group work implied in the Tutorial methodology.

FCI pretest data clearly confirmed that these groups are equivalent in their prior physics knowledge, which is otherwise very low, (26±11)% for the experimental group and (24±13)% for the control group. These results, compatible with the random answer (20% for FCI) have been shown to be statistically equivalent at the 0.001 level. The overall post instruction results are clearly different (67±15)% for the experimental group and (45±13)% for the control group, which are statistically different ($p<0,001$). These data allow us to calculate the normalized or intrinsic gain, defined as follows [14]:

$$g = (\langle Post\rangle - \langle Pre\rangle)/(100 - \langle Pre\rangle),$$

where <Post(Pre)> indicates the mean course performance (%) after (before) instruction.

The course that used Tutorials obtained an intrinsic gain g=0.56, which about doubles the gain of the control group (g=0.27). The performance per FCI item of the experimental group is shown in Fig. 1.

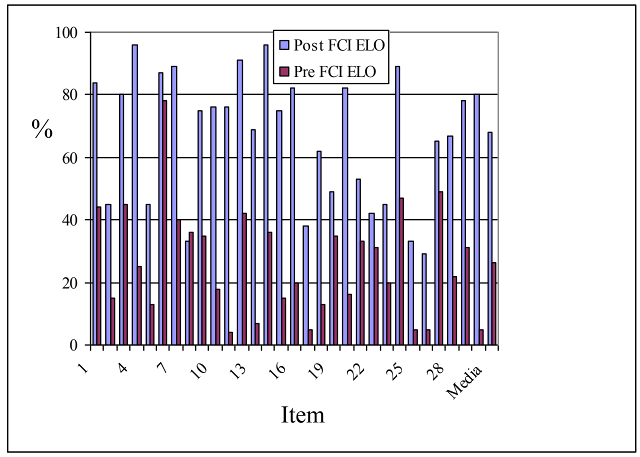

FIGURE 1. Pre (dark bars) and post instruction (Light bars) performance (%) of the Experimental ELO 2008 Group in the 30 items of the FCI Test. Last two bars on the right represent the overall class average. The intrinsic or normalized gain is g=0.56.

Fig. 2 represents the performance of the Control Group. It can be seen that only a few items show some improvement respect the pre-instruction situation, reaching an overall normalized gain of $g_{control}$=0.27. According to the wide study of Hake [14], this is a rather high gain for traditional teaching; therefore the present control sample could be considered an appropriate reference level of achievement.

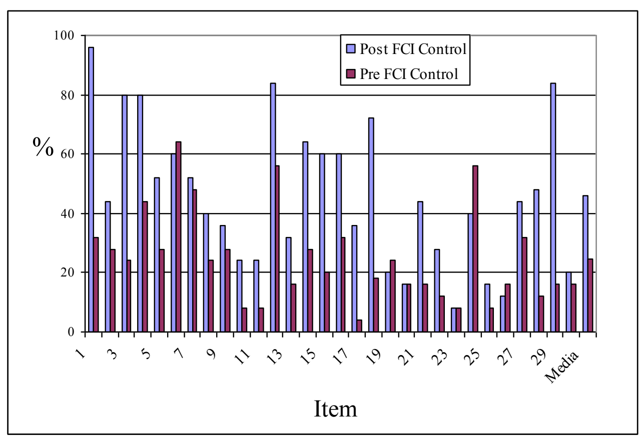

FIGURE 2. Pre (dark bars) and post instruction (Light bars) performance (%) of the Control Group in the 30 items of the FCI Test. Last two bars on the right represent the overall class average. The intrinsic or normalized gain is g=0.27.

Of particular interest for the local authorities is the fraction of students that reached a satisfactory level of understanding, *i.e.*, how is this overall gain distributed among the sample. Figs. 3 and 4 show student's pre and post instruction performance, for the Control and Experimental samples.

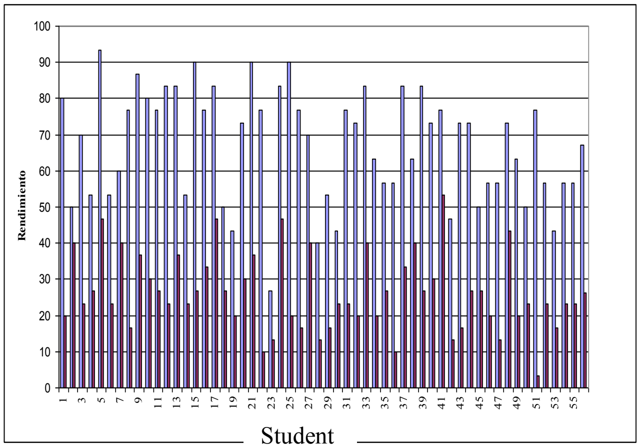

FIGURE 3. Pre (dark bars) and Post (light bars) performance for each student of the Experimental ELO 2008 sample. As before the last two bars on the right represent the whole class Pre and Post Instruction performance on the FCI.

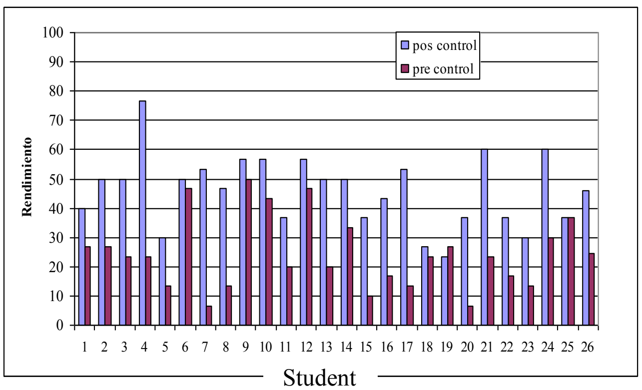

FIGURE 4. Pre (dark bars) and Post (light bars) performance for each student of the Control sample. As before, the last two bars on the right represent the whole class Pre and Post Instruction performance on the FCI.

Two features of these graphs are outstanding. The first is the important difference in the size of the two samples, roughly twice as large the Experimental group respects the Control Group. Since both samples were about the same size at the beginning of the course, the reduced size of the Control Group is just a manifestation of the amount of students that dropped out of the course during the instruction period (in all cases we have represented matched samples, *i.e.*, only those students that took both, pre and post, tests). The other important feature is that relatively important gains are obtained by just a small fraction of students in the Control Group (only 3 students reached the threshold level of 60%, indicated by Hestenes and collaborators [13] as the minimum level for problem solving), while the overall high gain seems to be shared by a majority of the students in the Experimental Group.

A linear correlation analysis [15] with post instruction conceptual knowledge as the dependant variable and the pre instruction knowledge and the group as independent variables, shows that, taken into account the small differences in Pre-tests, the linear model is good (adjusted R square=0.403), with the Group variable as the best predictor, with a difference between groups of 20.5±3.3; and an important size effect of 0.536 ($p<0.001$). The influence of the initial knowledge is more modest, with a size effect of 0.319 at $p=0.001$.

B. Using two Active Learning Teaching Strategies: Tutorials and Interactive Lecture Demonstrations (ILD's)

Interactive lecture Demonstrations is an active learning teaching strategy aimed at changing the traditional passive role of students in the lecture room. In the second experiment, in addition to the Tutorials used in the first experiment, four ILD's were used: Motion with cars, projectile motion, 1st and 2nd Newton's Laws and·3rd Newton's Law. They were instrumented as suggested by the authors, using MBL equipment. Contrary to our experience with Tutorials, which required about twice the students´ time that the original implementation (50 minutes per Tutorial), ILD's could be taught in about the 50 minutes suggested by the authors.

Fig. 5 shows the results of the ELO 2010 Experimental sample. A striking feature is that in the post test, this sample obtains more than 80% performance in 13 items, a very good degree of achievement.

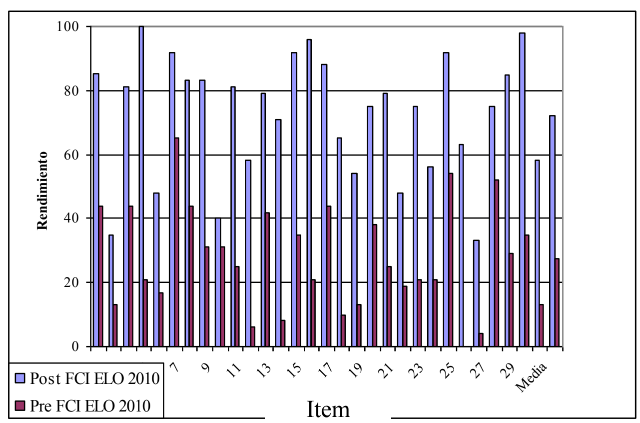

FIGURE 5. Pre (dark bars) and post instruction (Light bars) performance (%) of the Experimental ELO 2010 Group in the 30 items of the FCI Test. Last two bars on the right represent the overall class average. The intrinsic or normalized gain is g=0.62.

Pre and Post test results allow us to calculate an intrinsic gain of g=0.62, considered by Hake [14] a very good gain even for interactive engagement teaching methodologies. This performance improved in about 10% the conceptual learning obtained with Tutorials in the first experience.

The distribution of this high gain among the majority of students, a remarkable feature of Active Learning methodologies, is confirmed by Fig. 6, which shows that the average class result is higher than 70%, a remarkable result in our educational system. The figure also shows, even to the naked eye, that an important number of students achieve performances around or higher than 80%, which, according to Hestenes *et al*. [13] indicates mastering of the Newtonian framework.

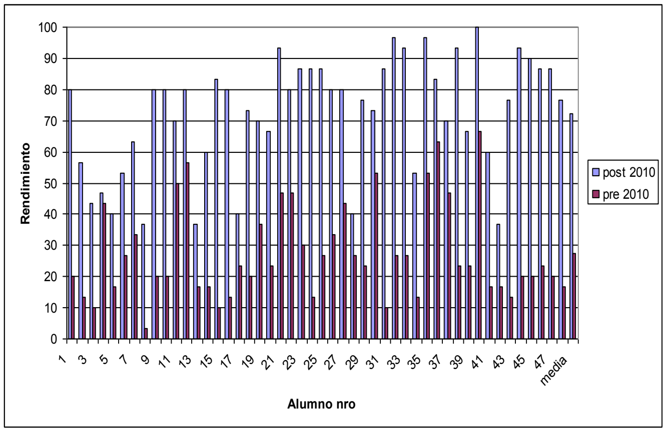

FIGURE 6. Pre (dark bars) and Post (light bars) performance for each student of the ELO 2010 sample. As before, the last two bars represent the whole class Pre and Post Instruction performance on the FCI.

In that regard it is important to compare, for the three samples, the fraction of students by quartile of student performance, shown in Fig. 7. Students in the two lower quartiles (performances lower than 40% and between 40 and 60%) have, according to Hestenes *et al.* [13], an unsatisfactory conceptual knowledge for problem solving.

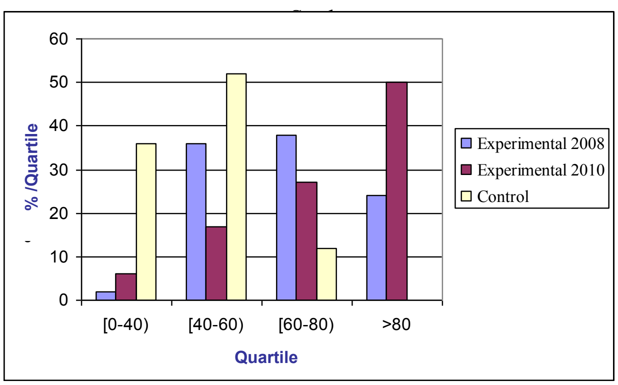

FIGURE 7. Student distribution by quartile of post instruction performance in the FCI test for the Control and Experimental ELO2008 and ELO2010 groups.

These authors show that a threshold knowledge of 60% is necessary for satisfactory problem solving. A large majority of students in the Control Group belong to these two lower quartiles, with only about a 12% performing above the 60% mark. On the contrary, in the Experimental Groups most of students perform above that threshold, showing that the use of active learning methodologies was very effective in fostering conceptual learning. Fig. 7 also shows the remarkable improvement obtained by using the two methodologies together, shifting about 50% of the sample to performances of 80% or larger, achieving, according to Hestenes *et al.* [13], a mastering level of the Newtonian framework.

C. The Institutional Evaluation

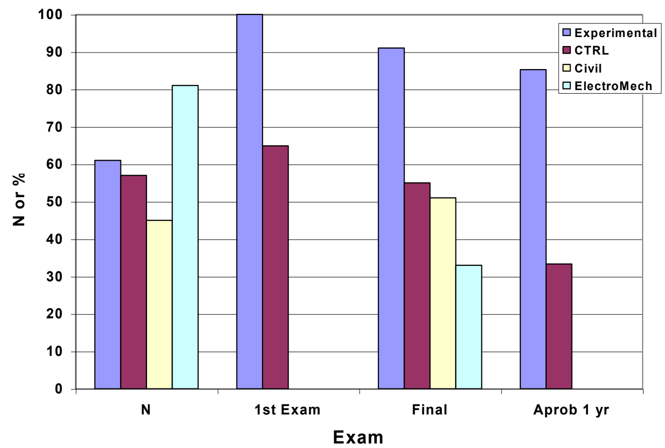

FIGURE 8. Enrollment N and fractions (%) of students approving the first partial exam, all partial exams and the course after one year, for the Experimental, Control, Civil and Electromechanical Engineering groups, respectively.

Institutional Evaluation (partial and final exams, consisting mostly of problem solving) is critical regarding what is considered the most important institutional problem in this region: students abandoning their university programs in their first year of study (drop out rate larger than 50% in Argentina’s public universities) and unusually high delays in their programs, for those students that remain in the system. Fig. 8 shows the situation for the students of this study. Here the Control and Experimental groups have been also compared with two other similar Physics courses, designed with the same curriculum and teaching conditions, but for the Civil and Electromechanical Engineering students, respectively. First group of bars indicate that the Control and Experimental courses have an enrollment near the average. Then we have the mean (%) performance of the corresponding students in the mid-term exam and final condition at the end of instruction. It is clear that the experimental group outperforms the Control group in the (identical) exam on Kinematics and Dynamics. The Final situation means the fraction of students that approved the exams during the instruction period. This indicates the fraction of student that will be able to enroll in the second physics course in the following semester. Those that fail will have their programs delayed by about one year. It is seen that the Experimental group largely outperforms the other 3 groups (almost triple the Civil Engineering group). Finally the last group of bars on right represents the fraction of students that approved the course within one year of finishing instruction (students need to pass an oral exam in some designated dates along the year). About 85% of the students in the Experimental group achieved that goal (which determines if they will graduate in a reasonable time), compared with only about 1/3 of the students in the Control group.

IV. CONCLUSIONS

The aim of this work has been to study the effect of applying active learning teaching methodologies in the Basic Physics university courses as a remedial strategy to solve two central problems of university education in Iberoamerican countries: The extremely low level of conceptual learning of physics and mathematics held by incoming university students and the very low level of achievement that these students have in the initial science (physics) university courses. The experiment was carried out in two steps: first we compared the results of traditional instruction (Control group) against an equivalent course were 5 Tutorials for Introductory Physics on Kinematics and Newton's Laws were introduced. In the second experiment we added 4 Interactive Lecture Demonstration to the curriculum of the Experimental group. Results show that: i) Experimental groups clearly outperformed the Control sample, doubling the intrinsic gain when using the FCI as a measure of conceptual knowledge. ii) The use of ILD's resulted in an improvement of student performance: not only the intrinsic gain was increased by more than 10%, but also the fraction of students with good learning improved, with more than half of the students scoring above the 80% level, considered the mastering the Newtonian framework [13], iii) the institutional evaluation (essentially problem solving exams) was remarkably higher for the Experimental Groups, which outperformed all other groups, being about three times more effective than the Civil Engineering Group in fostering passing grades for the students. The last feature is most important for determining the drop-out rate and the "retention" index, *i.e.*, keeping university student within their programs and without long delays. The above results clearly indicate that the use of successful, research-based, Active Learning teaching strategies is a very convenient way to follow if we want to drastically change learning achievements of Iberoamerican students in the basic physics courses. Upon the present results, their use should contribute in a substantial manner to solving two big university problems of the region: high drop-out rates and student's failure to finish their programs in a reasonable time.

ACKNOLEDGEMENTS

This work was supported by AECID (Agencia Española de Cooperación Internacional para el Desarrollo) Project C/018053/08 "Acciones para mejorar la formación de los alumnos de ciencias que acceden a las universidades iberoamericanas: planificación de intervenciones basadas en un diagnóstico de la situación y en la investigación en enseñanza de las ciencias". JCB is a Member of "Carrera del Investigador", CONICET, Argentina.

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