Journal of Science Teacher Education
DOI 10.1007/s10972-007-9054-7

Innovative Training of In-service Teachers for Active Learning: A Short Teacher Development Course Based on Physics Education Research

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In this contribution we describe a short development course for in-service physics teachers. The course structure and materials are based on the results of educational research, and its main objective is to provide in-service teachers with a first contact with the active learning strategy "Tutorials in Introductory Physics," developed by the Physics Education Research Group at the University of Washington. The course was organized in a constructivist, active learning environment, so that teachers have first to experience, as regular students, the whole Tutorial sequence of activities: Tutorial pre-test, Tutorial, and Tutorial Homework. After each Tutorial, teachers reflect on, and recognize their own students' learning difficulties, discussing their teaching experiences with their colleagues in small collaborative groups first and the whole class later. Finally they read and discuss specific Physics Education Research literature, where these learning difficulties have been extensively studied by researchers. At the beginning and at the end of the course the participants were given the conceptual multiple-choice test Force Concept Inventory (FCI). The pre-/post-instruction FCI data were presented as a practical example of the use of a research-based test widely used in educational research and in formative assessment processes designed to improve instruction.

Introduction

The learning of basic science principles in high school and universities is generally an educational priority in all developed societies. The substantial advances, in the last two decades, in the comprehension of the learning of experimental sciences, and in particular of physics, have led to the development of curricular material scientifically designed to improve science learning at the different levels of the school and university systems. The research in understanding the learning difficulties of physics at different educational levels, and the consequent development of curricular material, has given rise to a new, fast growing, field of research generally known as Physics Educational Research (hereafter PER). While new curricular developments continue to appear and different experimental applications show that the learning of the physical principles can be significantly improved (Hake, 1998; Redish & Steinberg, 1999) with the new methodologies that foster active learning, it can be safely said that, in the classrooms of the majority of educational systems, there has been little, if any change.

Different factors are contributing to this state of affairs, and in this contribution we propose to deal with a fundamental condition for change: teacher preparation for the new methodological approaches. In this regard there have recently been reports in the literature about comprehensive initiatives for re-preparing the physics teacher with the aim of changing local school systems (Stein, 2001) or even multinational programs for teacher education (Pintó, 2005). These extensive programs are indeed a very appropriate way to prepare teachers to change science teaching. They involve the availability of substantial resources, the need for getting together teachers from different places for extended periods of time, a non-trivial political decision about the characteristics of the school system, and so on. In many places these conditions are very difficult to meet, and a strategy of short teacher development courses is more feasible. With the aim of contributing to the latter teacher preparation strategy, we present in this report the objectives and characteristics of a professional development short course for in-service physics teachers (in this report we refer to physics teachers, both high school physics teachers and professors of introductory college physics).

The general approach underlying this course is to consider science teacher education in the general context of constructivistic learning, laying the foundations for an action-research oriented teaching practice. In other words, constructivism is seen not only as a theoretical framework to understand how pupils learn science, but also how teachers, building on their own experiences as teachers, actively construct their new knowledge about science teaching.

Consequently the central objective of this professional development course was neither to stress rigorous physics treatment nor general pedagogic approaches, but rather to develop critical physics teachers who, reflecting on their own teaching and profiting from the curricular advances provided by PER, are prepared to implement in their courses an iterative virtuous cycle of planning and executing instruction complemented with the formative evaluation necessary to provide the positive feedback for the next course implementation.

Within this framework, the course was designed to provide in-service physics teachers with first-hand knowledge of a teaching methodology that favors a deep conceptual learning of basic physics through the active participation of the students in constructing their own knowledge. The course therefore followed the recommendation of the National Science Education Standards (National Research Council, 1996) in the sense that professional development training of teachers "requires building understanding and ability for lifelong learning and should provide teachers the opportunity to learn and use the skills of research to generate new knowledge about science and the teaching and learning of science."

Therefore, the following basic features were included in the present course:

i. Participants reflect on their own experiences as teachers, pointing out the more common students' difficulties with the subject matter of each activity.
ii. The teaching strategy presented (Tutorials in Introductory Physics, McDermott, Shaffer, & PER, 1998, hereafter Tutorials) is a product of more than two decades of research in the teaching and learning of physics.
iii. Participants have to reflect on their own teaching experiences, comparing them with the learning model proposed by Tutorials.
iv. A research-based, multiple-choice test was introduced in the course in order to evaluate the results of instruction, reproducing as closely as possible the atmosphere of controlled instruction advocated for a regular physics course.
v. Participants have to read and discuss scientific literature reports relevant to the learning of the subject matter of each Tutorial activity.
vi. The basic features of collaborative learning were introduced and practiced by the participants in the small Tutorial groups.

The idea behind this course structure is that the use of the results, techniques, and language of educational research should prepare the in-service teachers to establish themselves as researchers, developing a critical view of their teaching, as a mandatory first step to improving their instruction (McDermott, 2001). In that regard the aim of the reflection and discussion about students' learning difficulties and teaching practices section is to help in-service teachers to shift their focus away from themselves as teachers toward their students as learners (Van See & Roberts, 2001). This discussion about learning difficulties also serves to elicit the knowledge that participants bring to a development course on methods of teaching science. Our position is that this "prior knowledge" should be taken into account as the starting point of any teacher development course if the active learning of science teaching, based on the general principles of constructivism, is a central course premise.

The article is outlined as follows. In section "Course Description" we present a summary of the course layout, with two particular subsections: the first subsection is intended to present and justify the use of Tutorials in a constructivist approach to developing conceptual learning and understanding of physics. The second subsection describes the use of a research-based, multiple-choice test in a controlled teaching environment of formative evaluation. In particular the Force Concept Inventory (FCI, Hesteness, Wells, & Swackhamer, 1992) test will be briefly described. Section "Results" summarizes the main results while conclusions and recommendations are presented in Section "Conclusion."

Course Description

The course was held at the central campus of the Tecnologico de Monterrey in Mexico. Since one of the instructors came from Argentina, and several participants from different regions of Mexico, the course had to be of short duration. These conditions, rather than particular of the present course, seem to be common to most teacher training courses. Given this time constraint and the above-mentioned course objectives, we arranged all course activities, in a tight 3-day schedule, under the following scheme: Figure 1.

The course started with the administration of the Force Concept Inventory test (FCI) before any Tutorial instruction (FCI Pre-test), and finished with the whole group discussion of the proposed active learning methodology, teacher practices and models of learning. The activities between Tutorial Pre-test and Analysis of PER results are iterated as many times as different Tutorials are worked through in the course (three in the present case). While the aims and characteristics of the Tutorial pedagogical constituents (pre-test, Tutorial, and Homework) are discussed in the next section, it is very important that teachers go through them in the same way as regular students are supposed to do. This process not only assures teacher knowledge of the subject matter (physics) and pedagogical activities, but it also gives them the possibility of anticipating students' learning difficulties, and preparing questions to guide that learning through an inquiry process.

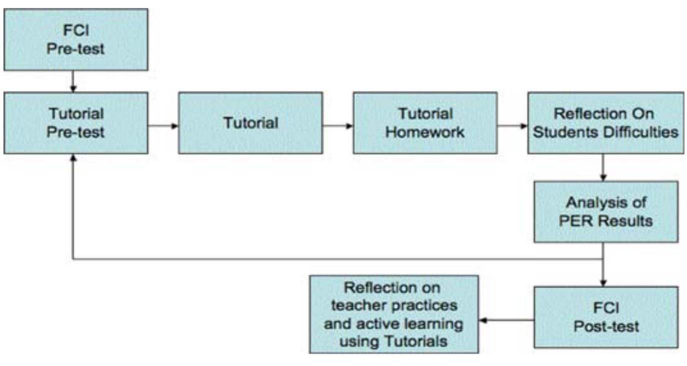

Figure 1. *General scheme of the course activities.*

The Reflection on Students' Difficulties section was included in order to identify such difficulties from the participants' teaching experience. It also helps participants to understand the kind of questions and problems that can be used to guide students' learning and to evaluate students' conceptual comprehension. Participants' contributions on the subject were compared and discussed against the results of educational research in the Analysis of PER Results section that ended each Tutorial cycle. This latter section was included in order to make the in-service teachers aware of the kind of information that can be obtained from PER literature. It seems clear that putting together that information with the knowledge and experience that the in-service teachers have about their own students is a necessary and fundamental step to improve instruction.

The final discussion was held just after the FCI was administered again as a post-instruction test and included not only an analysis of the main objectives and pedagogical approach of Tutorials, but also the value of teaching under a controlled atmosphere of formative evaluation.

The Teaching Strategy: Tutorials for Introductory Physics

As stated above, a main objective of this course was to introduce in-service teachers to a different environment of student learning. In general these teachers have experienced as (successful) students, and then practiced as teachers, a traditional model of teaching and learning in which the professor irradiates knowledge and where the students have a mostly passive role, listening to lectures, solving numerical, end-of-chapter problems, and following a detailed laboratory instruction guide, in case that any lab work is included in the course curriculum.

Results of different PER groups in the last two decades show that more effective learning is obtained through teaching strategies that favor active learning, i.e., the active participation of students in their own learning process. Specifically, regarding the teaching of basic mechanics at the high school and introductory university levels, data gathered by Hake (1998) show a marked difference in performance between students subjected to active learning methodologies as compared to those students that followed traditional learning. This conclusion has been confirmed in different educational systems, and for different subjects of basic physics (Benegas, Guidugli, Dequino, & Villegas, 2000; Engelhardt & Beichner, 2004; Maloney, O'Kuma, Hieggelke, & van Heuvelen, 2001).

These data make evident the convenience of changing the traditional teaching approach and embracing the new methodologies. A first step in that direction requires in-service teachers to break the "I teach as I have been taught" vicious circle. It seems therefore mandatory that in-service (and prospective) teachers experience (as students) active learning methodologies. In that regard, and among the several active learning methodologies that have been developed in the last decade as a practical result of

PER, Tutorials in Introductory Physics (McDermott et al., 1998) shows three distinct advantages: (a) it can easily be adapted to almost any kind of course structure or activities, since it covers the usual curriculum of basic physics, (b) it is very low demanding on classroom time, material, and human resources, and (c) literature reports (Redish & Steinberg, 1999) objectively indicate that Tutorials is one of the most effective teaching strategies for introductory physics. It seems important to note that, although Tutorials has been originally developed for university introductory courses, most of the material can, and has, been used with excellent results at the high school level.

Tutorials in Introductory Physics is a set of paper and pencil activities, complemented in a few cases with very simple laboratory equipment. The tutorial cycle (for every theme of basic physics) consists of the Tutorial Pre-test, the Tutorial itself, and the Tutorial Homework. The first and the last are individual activities generally taking place outside of the classroom, while the Tutorial is worked out during class time in groups of three or four students. In each Tutorial the students are initially presented with a rather familiar, simple situation, so the first activity can be understood by all of them. From there on students' learning is guided by inquiry, confronted sometimes with different alternatives, so conflict between previous and new ideas is provoked and must be resolved by the students, with peer discussions facilitated by the instructor questions, in a Socratic-style dialog.

The teaching strategy can be summarized in three basic steps: setting student minds for the new material and eliciting their ideas about the concepts involved, confronting these ideas with evidence provided by the Tutorial and finally resolving the inconsistencies. The Tutorial Pre-tests serve mainly the first step, while the Tutorials and Tutorials Homework care for the other two objectives (McDermott, Shaffer, & Somers, 1994).

For the present 3-day in-service teacher development course in mechanics, we have chosen the following Tutorials: "Representation of Motion," "Newton's Second and Third Laws," and "Changes in Energy and Momentum." These Tutorials use quite different teaching material resources: microcomputer-based electronic motion detectors, just paper and pencil (like most of the Tutorials), and a simple, very low-tech experimental equipment (a cardboard ramp, and a steel ball). These different experimental techniques are used to develop conceptual understanding of kinematic variables, Newton's Laws, and the energy and momentum changes due to a net force that acts in the direction (or at an angle) with the direction of motion.

Formative Evaluation: Using the Force Concept Inventory to Improve Instruction

In this teacher development course a central issue was the use of formative assessment to improve instruction. We strongly advocate throughout evaluation of course procedures and results in a cyclic process of planning, executing, and evaluating instruction in order to improve teaching and learning. A key point in this process is to select an evaluation instrument consistent with the goals set for instruction. Considering that Tutorials in Introductory Physics addresses the issue of conceptual learning of basic Newtonian mechanics in contexts closely related to physical reality, it seemed very appropriate to introduce the multiple-choice test Force Concept Inventory as an example of a method to evaluate student learning. FCI is one of the few scientifically developed multiple-choice tests based on the extensive research on student understanding of the main concepts of elementary physics. Since FCI includes as distractors a rather complete taxonomy of alternative conceptions and learning difficulties, it has been shown to be very helpful in determining the degree and extend of these difficulties in a particular student population. Administered for instance at the beginning of instruction (pre-test), the FCI yields fundamental information to program a more adequate instruction, properly suited for the corresponding student population (Fernandez Gauna & Benegas, 2002; Savinainen & Scott, 2002). Systematic results in the field of PER have also shown that this kind of test, administered before (pre-test) and after instruction (post-test) provides an objective measurement of the impact of a teaching strategy in the conceptual learning of mechanics. It also allows for important comparisons of different student populations (Hake, 1998). These characteristics made the FCI an excellent choice for a practical example of how to implement a virtuous cycle of planning, implementation and evaluation of instruction.

The FCI is a 30-item multiple-choice test developed by Hestenes and his collaborators at Arizona State University to monitor students' understanding of the concept of force and the related kinematics. The authors divided these subjects into six complementary conceptual dimensions: Kinematics, Newton's First Law, Second Law, Third Law, Superposition Principle, and Kinds of Forces. These six dimensions are probed by 30 items, each with five different options as possible answers. The wrong options (distractors) correspond to the more common alternative conceptions and students' difficulties with the concepts of force and motion, using information from several reports in the Physics Education Research field. According to this structure, the pre-instruction administration of FCI provides a very helpful "radiography" of student difficulties with the concept of force, i.e., the obstacles that the instruction must resolve to help the students to acquire the appropriate Newtonian framework. Full versions of the FCI for academic purposes can be directly obtained (in different languages) from the authors (Hesteness, 2005).

As a further convenient feature, we note that introducing the participants to the FCI (and the basic bibliography on the test) provides them with a research tool that, besides introducing the participants to fundamental knowledge of the alternative conceptions of force and motion common in any classroom, has sometimes bridged the initiation of critical teachers into educational research. As a rather new research field Physics Education Research has been born and it is growing with the active participation of researchers from other areas of Physics and Education, as well as with highly motivated and critical physics teachers. We think that any teacher development course should have this goal included, at least in its "hidden curriculum."

Reflection and Discussion of Students' Difficulties and Analysis of PER Results

In the final activity at each Tutorial cycle, participants have to reflect upon the most common learning difficulties that their own students have on the physics concepts covered by the respective Tutorial and later read and discuss literature reports relevant to it. The activities were structured as follows:

- Discussion in the small Tutorial group. In each small group the participants discussed their students' misconceptions and learning difficulties, writing on a whiteboard a list of those learning obstacles they considered most relevant.
- General discussion. The small group activity was immediately followed by a general discussion, in which each group presented the list they had agreed upon. All participants and instructors freely participated in these discussions, commenting on similar difficulties or expanding the presentation.
- Reading Physics Education Research literature. Participants read one relevant piece of PER literature on the topic (for instance McDermott et al., 1994). In that way they obtained a first-hand contact with the results of educational research, comparing students' learning difficulties reported by reputed researchers with what they have just discussed in the small groups.
- Closure by an instructor. General group discussion was always closed by a brief summary given by one of the instructors, with the further objective of informing about the state of the art on research and curriculum development on the subject.

Course Participants

The development course was attended by 25 in-service teachers: 16 college professors and nine high-school teachers. Their teaching experience ranged between 1 and 30 years, while their ages ranged between 25 and 60 years old. Ten of the attendants hold Ph.D. degrees, while eight hold M.Sc. degrees, six hold B.Sc. degrees, and one holds an M.D. degree.

Results

We will next summarize the results of the following main features of the teacher development course: (i) teaching and learning using Tutorials for Introductory Physics, (ii) formative assessment and the use of FCI, and (iii) analysis of the conceptual difficulties and alternative conceptions that participants and their own students show regarding force and motion.

As noted before, we consider a fundamental characteristic of any teacher development course that all participants practice the new teaching methodology exactly in the same way as students are supposed to. Even though Tutorials are not intended for individuals who already understand the underlying physical concepts, it is noteworthy that all participants worked actively, with enthusiasm and dedication through all Tutorial activities. The inherent inquiry format of Tutorials very often promoted lively discussions in all groups. When participants (re)discovered concepts or ideas which they had not thought about, for a long time, they felt excited and this fact promoted even more discussions. For that reason, even though each Tutorial had been planned as an hour-long activity, in the present application it took generally longer, for all groups and for every Tutorial. The in-depth conceptual discussions promoted by the Tutorial worksheets provided vivid moments of second time learning. This phenomenon, which we consider very important for teacher development courses, is readily shown by the intense discussion that happened among members of one group during the Newton's Second and Third Law Tutorial. The controversy was resolved by the own group members, after some Socratic dialog conducted by one of the instructors. In the middle of the discussion, one of the participants, a college professor holding a Ph.D. in physics, stood up, grabbed his head and said aloud: "Oh my God, I have taught this thing wrong for the last ten years". We believe that this type of "second time" learning increases the credibility of the teaching strategy among experienced teachers, and therefore its possibilities of being adopted for classroom use.

In order to exercise formative assessment and to practice instruction as close as possible to a well-controlled introductory physics course, the FCI was administered as a pre-instruction test (FCI pre-test) at the beginning of the course, and as a post-instruction test (FCI post-test) just after finishing all Tutorial activities. Although the answer sheet was anonymous, each participant had chosen an identification number that allowed them to individualize and analyze his/her own FCI pre-/post-test data. A simple Excel file permitted a fast analysis of individual and group FCI data. In this way the discussion of FCI results and their use in programing and assessing instruction were carried out just after the FCI post-test was administered.

The general results of the FCI pre-/post-tests are as follows:

(a) The overall pre-test course score was 79%, very close to the figure suggested by Hesteness et al. (1992) as the minimum value that indicates mastery of Newtonian thinking.
(b) The teachers were particularly interested in their "weak" points, in particular in the non-Newtonian conception that a net force in the direction of motion is always needed, even in the case of non-accelerated motion. Average pre-test results indicated that about 30% of the participants hold this alternative conception, while the pre-Newtonian idea of impetus attracted between 20% and 25% of this population. Of particular relevance to uncovering these alternative views resulted from the analysis of those items where a force perpendicular to the direction of motion is applied.
(c) Although it was not a central objective of the present course to develop the conceptual understanding of Newtonian mechanics in this student population, we note that the FCI post-test results revealed important improvements in the following conceptual aspects: the force proportional to velocity misconception decreased from 31% to 19%, while the impetus idea was prevalent only in 11% of the population against the 22% before instruction (these figures are average values for all items that probe the corresponding misconceptions).To no surprise, Physics Education Research results have already recorded (McDermott & Dewater, 2000) the appearance (and persistence) of non-Newtonian conceptions in populations of advanced physics instruction. As shown by different studies (Hake, 1998), these deficiencies are typical of the traditional instruction, which the participants were subjected to as students, and practiced later as teachers.

The main results from the final general discussion on the main characteristics, use and results of FCI were the following:

(a) Participants were particularly interested in their "weak" points, in particular in the non-Newtonian conception that a net force in the direction of motion is always needed, even in the case of non-accelerated motion.
(b) Participants stated that the different items of FCI seemed relevant to evaluate conceptual learning of force and motion.
(c) Participants stated that, in several cases, they had to give second thoughts to a question, in order to decide on the correct answer, indicating that distractors were considered very attractive options.
(d) Participants realized that their own misconceptions were not usually tested in their own courses. They agreed on the necessity to include appropriate conceptual questions in future evaluations.The vivid discussions generated by the above results alerted the participants about the

importance of teaching for conceptual learning and, in particular, about the need to improve and extend the teaching of motion in two dimensions, including examples in different contexts to understand the effects on the direction of motion of forces which are not aligned with that direction.

The reflection and discussion about student learning difficulties section was very significant for teachers. In their own discussions, they found many of the learning difficulties that PER has investigated together with some others. They realized that no matter what language they speak, the educational level or where the class is held, physics students have similar learning difficulties, which usually come from everyday experience. As an example of the product of these discussions at the end of the Tutorial on Newton's Second and Third Laws (McDermott et al., 1998), the following student difficulties were considered the most relevant by the participants:

1. Difficulty on isolating the system and drawing the corresponding free-body diagram (FBD).
2. Difficulty in understanding that constant velocity means zero acceleration and therefore, zero net force.
3. Difficulty in identifying third law pairs.
4. Assumption that the normal force is always equal to the weight. Transmission of forces through objects.
5. Inclusion of the net force on FBD.
6. Inclusion of the acceleration or even velocity on FBD.Some of these difficulties have been investigated in different PER reports (Clement, 1982; McDermott et al., 1994), but others, like six and seven above, are less common in the literature and might be a consequence of a particular instruction method. It is interesting to note that the main conceptual difficulties of the participants themselves (related with the ideas of impetus and force proportional to velocity) were, in general, not included by them as important learning obstacles of their own students, emphasizing implicitly the difficulties that any teacher has in identifying his/her own conceptual weaknesses.

In analyzing students' learning difficulties and the characteristics of the teaching strategy, participants realized the enormous amount of research that went into the development of Tutorials and how basic research has been used to develop curricular material specifically designed to address these learning obstacles. They found how researchers approached the study of different learning problems, understanding even more deeply the value and importance of active teaching–learning strategies based on educational research.

Conclusions

The aim of this contribution has been to describe the main features and objectives of a short professional development course for in-service physics teachers working in Mexican universities and high schools. The course has been modeled under the constructivistic premises of active learning and consisted of a 3-day meeting where the participants worked intensively through three (mechanics) examples of the research-based teaching strategy "Tutorials in Introductory Physics."

The main objective of this training course was to provide the participants with a first hand, practical contact with an active learning teaching strategy in order to break the close cycle of "teaching as I have been taught." The course was designed to allow the participants to experience active learning as learners, so they followed the Tutorial materials as if they were regular college or high school students. This work set their minds for the next step, where they discussed and elaborated as reflective teachers about the teaching material and about their students' difficulties in learning the subject matter. In the next activity participants compared their observations with the main findings of Physics Education Research and reflected on how each Tutorial addressed those learning difficulties. To that end the sequence proposed in this course: working through the whole Tutorial material first (Tutorial pre-tests, Tutorials and Tutorials Homework), elaborating and discussing their own students' difficulties on the subject, and finally reading and discussing a scientific paper relevant to the teaching and learning of the topic, proved very efficient (and motivating) in eliciting teacher's previous ideas about the learning difficulties of their students and how their teaching practices affect this learning. In this way the participants had a further chance to understand the objectives and value of the extensive research, with its cycle of implementation and testing, inherent in the development of each Tutorial.

A second objective of the course was to provide the participants with a working example of how formative assessment can be used to improve the quality of teaching. To that end the Force Concept Inventory, a research-based multiple-choice test systematically used in research in physics education, was presented. This test has also been shown to be a relevant tool for planning and evaluating instruction in formative assessment processes for improving instruction. In our experience the FCI test, being based on extensive research on the major and more common learning difficulties and alternative conceptions of force and motion, proved to be a very valuable tool to introduce participants to these research results. In this application, the participants could compare the results with their own teaching experiences which were brought forward in the "Reflection and discussion of students' difficulties" section. Regarding the FCI pre-/post-test results, the participant could now have first-hand knowledge of their own conceptual assets and difficulties. As an example, the participants realized that their own most prevalent difficulties related to the effects on the direction of motion of forces, which are not aligned with that direction and the non-Newtonian idea of impetus. These persistent difficulties, even among a population with a strong content background in physics, like the participants in this course, alerted in-service teachers for the need to improve in their courses the instruction of two-dimensional dynamics, with real-life examples to illustrate different physical circumstances.

Although it must be emphasized that the aim of introducing the FCI was neither to determine teachers' prior knowledge nor the degree of improvement (if any) in their conceptual knowledge of force and motion after this short development course, it is interesting to note the overall group improvement in those FCI questions related to the material covered by the three Tutorials practiced in this course. Although this gain could be attributed to other factors, besides the "Tutorials" instruction undergone in this course, the effect of just a pair of Tutorials on the conceptual comprehension of a specific subject has been previously pointed out by Abbot, Saul, Parker, and Beichner (2000).

Overall, we think that the objectives chosen for this course were realized. In that regard it seems important to note that as a practical result of this teacher development course, the host institution has decided to implement Tutorials in all elementary physics courses (around 1500 students) and a similar project is underway in a net of four local high schools.

Acknowledgments

H. A. acknowledges financial support from the Tecnológico de Monterrey Research Chair in Optics under Grant CAT-007. J. C. B. acknowledges the financial support of the Tecnológico de Monterrey for his participation in the course here described. Part of this research has been carried out under the Project P-320102 financed by the Universidad Nacional de San Luis, Argentina.

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