

**ACTIVE LEARNING COMBINED WITH CLASSROOM RESEARCH:
AN EFFECTIVE METHOD FOR THE PREPARATION OF PHYSICS TEACHERS AND
PHYSICS MAJORS**

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Abstract

Currently most universities teach introductory physics using separate lecture and laboratory sessions. Students frequently perceive them as two different courses. In a traditional physics lecture most of the class is devoted to presenting material from the textbook or the professor's notes. The material is written on the board, and the students take notes. The purpose of the laboratory usually is to corroborate some result or fact previously discussed in the lecture or revealed in the laboratory manual, and many of the laboratory experiments are conducted following "recipe" type instructions. In this article we discuss an alternative to the traditional scenario with results on the effectiveness of this new course.

Background

In 1992 a group of physicists from different Puerto Rican universities assembled to conduct an assessment of the introductory physics course¹. The study used the "Force Concept Inventory" developed by Hestenes and Wells (1992) as both a pre-test and post-test to measure conceptual understanding of physics. The sample consists of 1,200 students selected randomly from all students enrolled in the introductory physics course at five universities. Because of time constraints only the first fifteen questions of the "Force Concept Inventory" were used. The pre-test mean was 27%; the post-test mean was 35%. From their findings in this assessment Alonso, Orengo, Martínez, Cersosimo, and Peñalbert (1997) concluded that: "...the traditional teaching

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methodology used in the introductory physics course is not effective in developing thinking skills and conceptual understanding in the students.” This conclusion is consistent with former American Association of Physics Teachers president Robert Hilborn’s (1997) remarks that there is evidence that traditional courses taught with passive lectures fail to meet the goals of the introductory physics course.

Integration of lecture and laboratory

One professor involved in the Puerto Rico study chose to integrate the lecture and the laboratory sessions using a constructivist approach to promote active learning to improve the effectiveness of the introductory physics course. The goal was to put the student at the center of the teaching-learning process (McDermott 1991). Rather than the traditional course arrangement with four one-hour lecture sessions led by a professor and a separate two-hour laboratory session led by a graduate teaching assistant, the integrated course consisted of a three two-hour sessions per week. The integrated approach used standard lab equipment, but it also made use of Calculator-Based Laboratory™ (CBL) technology. With the CBL, a graphic calculator and the use of sensors, the course took advantage of real-time data collection and analysis to introduce concepts.

Besides taking advantage of technological innovations, the integrated course employed some of the best innovations from other physics educators. The classroom-laboratory environment promoted in the integrated course was similar to the workshop environment in Priscilla Laws’ Workshop Physics (1991) at Dickinson College with the major difference being the use of more cost-efficient, mobile technology rather than computers. The integrated course also relied heavily on the peer discussion based on Eric Mazur’s successful model at Harvard (1996).

The constructivist model

The integrated class has been coupled with research on student’s understanding of physics to help create an activity-based learning environment. Figure 1 diagrams the model used to transform the traditional lecture session into an active, guided discussion. The integrated classes typically starts with a brief introduction illustrating the pertinence of a concept. Then a **situation** that bears the concept is posed. The **situation** asks a clear question. This creates the foundation for the **individual prediction**. Each student is asked to make his/her own prediction without consulting anyone. The professor then collects the representative **individual predictions** and presents them to the class. Sometimes, a few students are selected to justify their predictions. This allows the professor to assess preconceptions or misconceptions. Then the students are paired or combined into small collaborative groups to engage in **peer discussion**. The objective of the **peer discussion** is for each student to defend his/her prediction. Besides allowing students to communicate, this provides a comfortable atmosphere for students to reason. The idea for this came from Eric Mazur (1996).

After the discussion period, the professor allows students to submit **revised predictions** from their groups, if they want to do so. As before, each **revised prediction** is submitted to the class with a brief justification. Very often the students’ **revised predictions** are correct or very

close. New considerations brought by peers rarely are misleading. Even if the revised predictions are incorrect, they are given equal consideration.

The predictions and discussion processes seemed an improvement over the traditional lecture format by themselves; however this format has been combined with the laboratory. Immediately following the **revised predictions**, an **experiment** is conducted, with the aid of traditional or modern technology. Using the appropriate sensor with the CBL, the students can run the experiment and receive a simultaneous real-time graph with the aid of the calculator. A professor can modify this for a large lecture hall by conducting a demonstration of the experiment using a Liquid Crystal Display (LCD) Viewer connected to a projectable calculator. The results would then be displayed on an overhead projector.

This process serves the purpose of **validation**. It helps students confirm or reject their **revised predictions**. In general, it leads to three possibilities: a **new experiment**, **new questions** or a **generalization**. If experiment results are inconclusive or hard for students with misconceptions to accept, the professor proposes a **new experiment** emphasizing the control of variables. If the experiment goes well and is accepted by students but many preconceptions and misconceptions were detected in earlier stages, the instructor poses **new questions** to ensure a deeper understanding of the concept. If the experiment goes well and few misconceptions were detected in earlier stages, the professor uses guided inquiry to help students produce a **generalization** that explains the observed behavior. To obtain the **underlying principle, concept and model**, the professor asks related questions, which in turn lead to a new **situation**. This approach contrasts the traditional passive *teaching by telling* by making the student the center of the class rather than the professor. The final stage of this constructivist model allows for **applications**; where the conceptual or mathematical model is used to solve related problems.

Benefits of the integrated strategy

This approach contrasts the traditional *teaching by telling* method by nicely blending lecture and laboratory periods to produce an active, integrate learning environment. The lecture-laboratory integrated environment promotes active learning because the students participate in hands-on and brains-on activities. With this inductive approach, the students are involved in critical thinking adventures that prepare them to pose and formulate better questions and to supply more thought-filled answers. This approach capitalizes on the student's natural curiosity. It emphasizes both discovery and exploration allowing students to proceed from the concrete to the abstract.

It has been noted that student-student and teacher-student interactions have been augmented by this approach. Students become more talkative and express their views more readily. This helps alert the professor to student misconceptions that otherwise might not have surfaced. The de-emphasis on lecturing stimulates student participation and student interest. Mathematics and physics are no longer seen as separate, unrelated subjects in this environment because the model makes them an integrated entity. The use of the graphic calculator, besides promoting an inexpensive and portable technology, helps to narrow the existing gap between math and science.

Assessment

The approach has been used in a series of courses and workshops for in-service high school physics teachers and in the introductory physics course for physics majors. This semester the course is being offered to physics majors and pre-service physics teachers. Ninety five percent of the in-service high school physics teachers who have participated in the program have either a biology or general science background and teach physics due to the shortage of certified physics teachers at the high school level in Puerto Rico. The program offers them credit courses in physics, so they can become certified physics teachers and is sponsored by the Department of Education through the Title II, Part B. Dwight D. Eisenhower professional development program.

A series of diagnostic tests was given to the in-service teachers to probe their understanding of basic physics concepts. Although the results vary from one concept to another, they do show that in general, most of these teachers lack conceptual understanding of physics concepts. These results are similar to those obtained by other groups working on research in physics education (McDermott, Hestenes, Redish, Laws, Thornton and others) who have found that, in general, students in traditional lecture mode courses do not gain much conceptual understanding of physics. A large majority of the in-service teachers that took the tests aren't physics majors and therefore took one or two general physics courses at the university as part of their general preparation. The implications here are of utmost importance since it will be very difficult for anyone to teach something he or she doesn't understand.

To assess the effectiveness of the integrated course when offered to physics majors a series of pre-tests and post-tests was administered. The graph in Figure 2 shows the percentage of participants in the integrated course that obtained a wrong, an almost right and a right answer for two open-ended, discussion questions. An almost right answer consisted of enough right portions in response to give the student partial credit for his/her result. The circuit question asked if a light connected to a battery with only one cable in several ways would light or not. The intensity question asked students to select the order of intensity for three light bulbs connected in a particular manner. All students performed better on the post-test questions than they had on the pre-test.

For a comparison between the traditional and integrated courses, a series of multiple-choice questions were given. The number of correct answers increased dramatically in the post-test questions which were similar but not identical to the pre-test questions. Not only did students in the integrated class do better on these questions, they made statistically significant gains from the pre-test to the post-test, as seen in Figure 3.

In addition an open-ended questionnaire was administered to the participants in the integrated course. The evaluations were extremely good, but there is room for improvement. Students said² things like:

Sincerely I cannot think of anything to improve the course, however the seats in the room are uncomfortable to take notes seated for two hours.

² The students' comments were translated from Spanish.

Certainly the physical facilities must be adequate and rearranged to provide for better use of the available space. Another student commented:

It would be good to discuss more problems in class. To know the formulas without knowing how to apply them doesn't seem very useful to me.

There was time for problem solving but some students failed to comprehend that the process of determining an appropriate mathematical model is in itself problem solving. Care should be taken to clarify to the students all the different problem solving possibilities and to give them ample time to get involved in the process.

In terms of allotted time one student wrote:

There should be a better balance among the time devoted to the lab and lecture. Although the lab exercises are very thorough, it is necessary to devote more time to the theory. Many of us are not used to the type of reasoning demanded when trying to derive formulas and concepts from experiences as proposed by this course.

It is important to explain to students who are used to more traditional courses the reason for a different approach. If they fail to understand the justification of this integrated approach it is harder for them to accept it.

A sample of the most positive comments are summarized in the following expressions. A student wrote:

"...the course permits the student a better comprehension of physics. In other words, the student learns the theory at the same time he observes the why and how the things learned happen.

Another said:

It gives the student a sense, not that he is verifying, but that he is discovering.

Finally the comment that seemed to summarize the effectiveness and promising outcomes of the integration of the lecture and laboratory session:

...it is an excellent idea because many of the things in the normal course you have to learn them by faith, or because it was told by the professor, or by the book, in the present course the student had the opportunity to see the physics. By this I mean that we can see and conclude the origin of all the explanations and mathematics that help to predict the physics phenomena that describes the universe.

Applying Classroom Research

This semester more classroom research has been conducted as a part of a mini-grant from the Puerto Rico Collaborative for Excellence in Teacher Preparation (DUE 9753543). The research is being conducted with the physics majors and future physics teachers in the integrated course and the in-service teachers in the physics certification courses. The research is carried out in this manner: 1) administer pre-test to determine if any erroneous preconceptions exists; 2) use the

information from the pre-test to design instructional activities to help combat these misconceptions; 3) evaluate the students and the effectiveness of the activities using a post-test. The following has been done for the concept of friction. A two version diagnostic test was designed following Wittman, Steinberg and Redish free response multiple-choice format. The test posed questions with regards to the force of friction between an object placed in a perfectly leveled horizontal surface and the surface under different circumstances. The following misconceptions were identified as a part of the pre-test.

- The force of friction exists even in the absence of an externally applied horizontal force.
- The force of friction is responsible for the object being at rest even when there is no applied horizontal force.
- The force of friction has a larger magnitude than the externally applied horizontal force.

Figure 4 shows the large percentages of physics majors, future physics teachers, and in-service teachers who had misconceptions about friction. Figure 5 shows the improvement on the conceptual understanding of friction made by the integrated class compared to the traditional class. The integrated class significantly fewer misconceptions than the traditional class after instruction on this topic.

Based on the entire process, the following general conclusion was drawn. *Students benefit when instruction is tailored to address their misconceptions; they also benefit from active, discovery learning.* The following conclusions were made specific to the teaching of the concept of friction.

- Even though the existence of friction between two surfaces as a force that prevents “motion” of one surface relative to the other may be intuitive or common sense, its specific and more detailed behavior as two distinct forces does not seem too obvious.
- Friction is a complex concept that requires special attention.
- The order in which the Laws of Motion are usually taught adversely affects their comprehension.

The first conclusion is drawn from the large percent of students (>80%) that failed to recognize that the force of friction appears the moment the object would tend to move as a response to an externally applied force and not then. This large number of incorrect responses was reduced to a still relatively large value (54 %) after traditional classroom instruction. This number is consistent with the percentage of in-service physics teachers (that most likely learned the subject in the same manner) that also had the same incorrect idea (57 %). In the case of the physics majors and in particular the physics teachers, however, this figure is unacceptable for reasons discussed previously.

The second conclusion is based on the fact that the idea that *friction is responsible for the objects being at rest even in the absence of an externally applied horizontal force* still prevails (51 %) even after going through activities specifically designed to deal with the student difficulties on this subject.

The third conclusion is drawn mostly from experience teaching the concept and the fact that the *force of friction* is single-handedly the ‘culprit’ for the common sense “Aristotelian” belief that *a force is needed for an object to stay in motion*, instead of the correct interpretation based on the concept of *inertia*.

Final Comments

The amount of information and detail available today about the way the physical world works is several orders of magnitude larger than what was available say, thirty years ago. In our case, we have been learning it throughout the years. This puts a lot of pressure as to the effectiveness of the teaching learning process, in particular in the case of students majoring in physics and specially for pre-service and in-service teachers in the process of retraining.

Active learning strategies combined with those that address students' difficulties with the subject have been shown to work and should be the ones employed in courses for physics majors and pre-service physics teachers.

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Figure One

Constructivist model used to transform the traditional lecture into an integrated course.

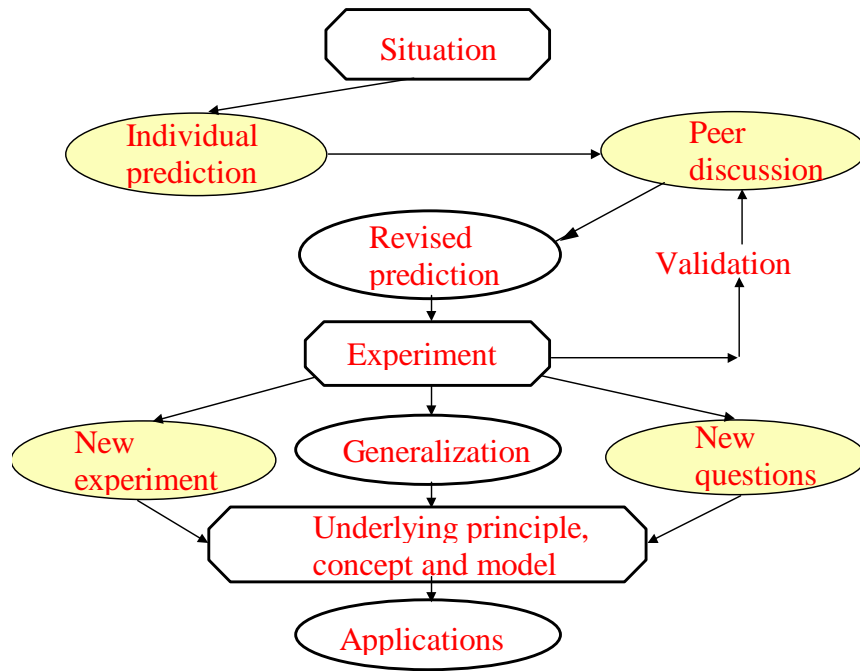


Figure Two

Results for students in the integrated course on (pre-test and post-test) open-ended, discussion questions on the topics of circuits and light bulb intensity.

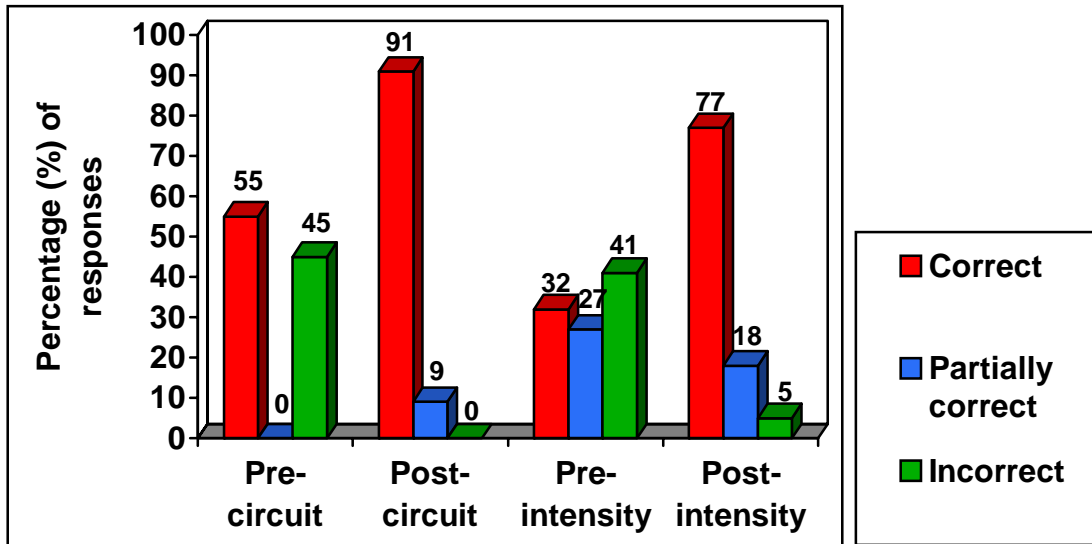


Figure Three

Results for students in the traditional and integrated courses on a series of pre-test and post-test multiple-choice questions on the topics of circuits and light bulb intensity. (Both tests had 15 questions.)

Students in . . .	Pre-test Mean	Post-test Mean	Increase from Pre-test to Post-test
Traditional Course	4.8	6.0	1.2
Integrated Course	6.7	11.6	4.9

Figure Four

Results on the friction pre-test questions for students in the integrated course and for in-service teachers in the workshop. These numbers represent the percentage of participants who were found to have incorrect preconceptions about the concept of friction. (Note only those questions involving friction are included.)

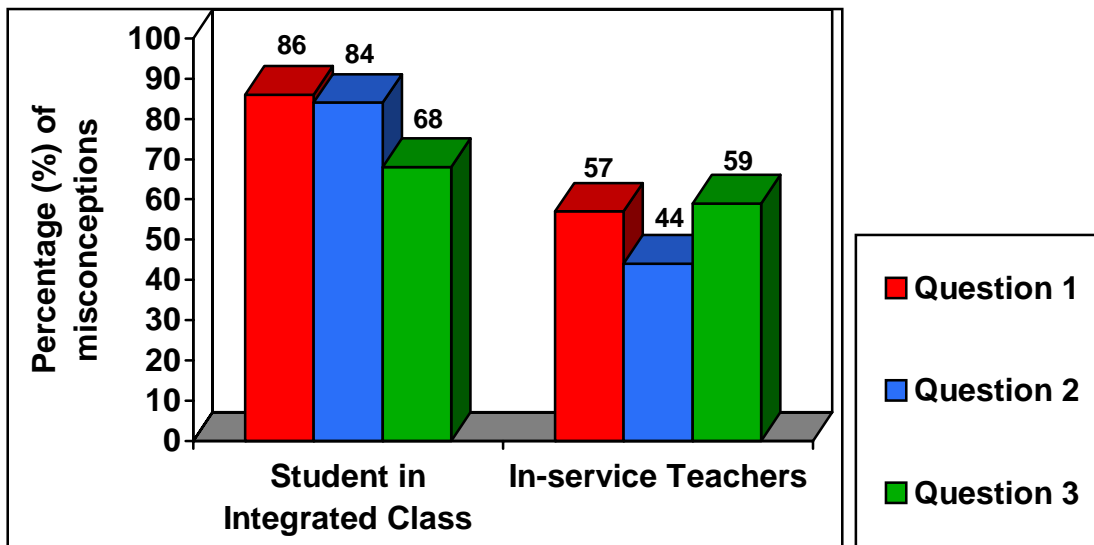


Figure Five

Comparison of the pre- and post-test results on the friction pre-test questions for students in the integrated course, in-service teachers in the workshop, and students enrolled in the traditional course with a separate laboratory.

