Does pedagogy influence gains and losses of conceptual understanding?

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The pre-post instruction answer dynamics to the research-based, multiple-choice, single-response test DIRECT, has been used to study the effect of traditional and active learning pedagogies on gains and losses of conceptual knowledge induced by instruction. Our results suggest that, for high school students of a Latin American education system and on the subject of simple DC electric circuits, these features seem to be strongly influenced by the teaching approach. In particular our data suggest that the active learning strategy Tutorials in Introductory Physics is clearly more efficient that traditional instruction, increasing by a factor of two the gain induced by instruction and furthermore, decreasing losses by a similar factor. It is also found that, even using this successful teaching methodology, an important fraction of students need further actions to acquire sought scientific knowledge. It is suggested that reinforcing this instruction with a few, but pedagogically coherent, active-learning activities could further improve learning outcomes, improving therefore the efficiency of instruction to boost conceptual learning, a much needed challenge for science education in most Latin American countries.

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1. Introduction

A recent article by Lasry, Guillemette and Mazur [1] warned that, after instruction, some students gain conceptual understanding but others seem to lose knowledge. In that sense, they view instruction as a "two steps forward, one step back" process that can be quantitatively studied through standard pre-post instruction testing using research-based, multiple-choice, single-response (RB-MCSR) tests. These authors analyzed the options selected by students before (Pre) and after (Post) instruction in every test item, measuring the frequency of appearance of all possible (Pre, Post) answer pairs. They considered data from different samples formed by high school, college and university students that had taken a basic mechanics course, and used the Force Concept Inventory (FCI) test [2] to evaluate conceptual understanding of force and motion. Surprisingly, the authors found that a relatively high abundance of correct answers before instruction turned to incorrect after instruction. Under their experimental conditions, this "unlearning" problem was of significant magnitude, since about one third of students appeared to lose knowledge. Analyzing these results as a function of previous knowledge (as given by the pre-instruction application of the same RB-MCSR test), they found that students with low initial knowledge have lower gains and higher losses than students that enter the course with higher knowledge of the subject matter. This problem is smaller, but still relevant (15% loss), for those students with high pre-instruction knowledge, most of them attending the participating top tier universities. The authors warned that other factors influencing learning, such as type of instruction, socio-economic conditions, gender, motivation, etc., might affect these results.

At this point, it is worth noting that in research-based MCSR tests, the different distractors (the wrong options) are obtained from previous qualitative and quantitative research on the learning difficulties and alternative models of the tested subject. Therefore, the analysis of the popularity of the different distractors provide a "radiography" of the different alternative models held by a given group of students. In that regard, Bao and Redish [3] pointed out that alternative conceptions of a particular topic seemed to be limited to a few popular models, and that different contexts could activate different, and even contradictory, conceptions. In this framework, it is expected that an individual with a solid scientific framework should, ideally, answer all items in a consistently correct manner, but others - specially uninstructed participants - could choose different wrong answers, even shifting from to one distractor to another without a solid reason. Consequently, analysis of the (Pre, Post) answer pairs using research-based multiple choice tests provide very important information, not only regarding students that gain or lose knowledge through instruction, but also about those students that fail to learn, defined here as those that select alternative models before and after instruction.

In this framework, the main objective of this contribution is to study the influence of the type of instruction on gains and loses of conceptual knowledge by high school students of a Latin-American education system. To that end, the method described below has been applied to two equivalent high school classes; one that followed traditional, teacher-centered pedagogy, and another that followed the teaching activities provided by a well-known active learning teaching strategy.

2. Methods

In this work, we use the approach proposed by Lasry *et. al.* [1] to reanalyze data already published [4] to study the effect of the pedagogical approach on gains and losses of conceptual understanding. This classroom experience concerns the teaching of simple resistive electric circuits to students attending the 11th year of instruction in a state-run high school of San Luis, Argentina. Two mixed-gender classes (called "divisions") with a similar number of students of both sexes, coming from low to middle class families, were used in the experiment. One division was randomly selected as the control sample (CRTL), while the other was considered the experimental group (EXP). Except for the type of instruction, traditional teaching in the CRTL class and Tutorials in Introductory Physics [5] in the EXP class, all educational conditions were equivalent. Benegas and Sirur Flores [4] includes a detailed description of student samples, teacher, school conditions and implementation details of both types of instruction.

Conceptual learning was measured with the 29-item, MCSR test DIRECT [6], that measures conceptual knowledge of simple resistive electric circuits. The 29 items probe into 11 particular learning objectives, which the authors grouped into four general objectives: Physical aspects of DC electric circuits, Energy, Current, and Potential Difference. The instruction of this experiment did not cover those objectives related with energy and microscopic properties of electric circuits [4]; therefore, analysis of the corresponding items is not included in this report. DIRECT was administered at two different times; just before (pre-test) and after (post test) instruction, which are referred as Pre and Post throughout this work.

As an example of the analyzed data, Fig. 1 shows the evolution of students' answers to Item 22 of DIRECT from before (Pre) to after (Post) instruction.

This example shows some important points. For the CTRL sample the most abundant answer pair correspond to those students (15) choosing different wrong answers before and after instruction, followed by those selecting the same incorrect answer pair (6) and those changing from an incorrect answer before instruction to the correct one (6) after instruction. Finally, the four student choosing the correct answer before instruction selected a wrong one after instruction. On the contrary, in the EXP class the dominant answer pair corresponded to those students (24) that evolved from a wrong answer before instruction to the correct one after it.

Similar data for all relevant items enable us to determine the class mean values of the five possible (Pre, Post) answering pairs: correct to correct (CC), correct to incorrect (CI), incorrect to correct (IC), incorrect to same incorrect ($I_=$) and incorrect to different incorrect ($II_{\neq}$). The use of a research-based, multiple-choice test provides pedagogical significance to the different answering pairs. For instance, it let us to discriminate between those students who selected the same wrong option ($II_=$) from those choosing different distractors

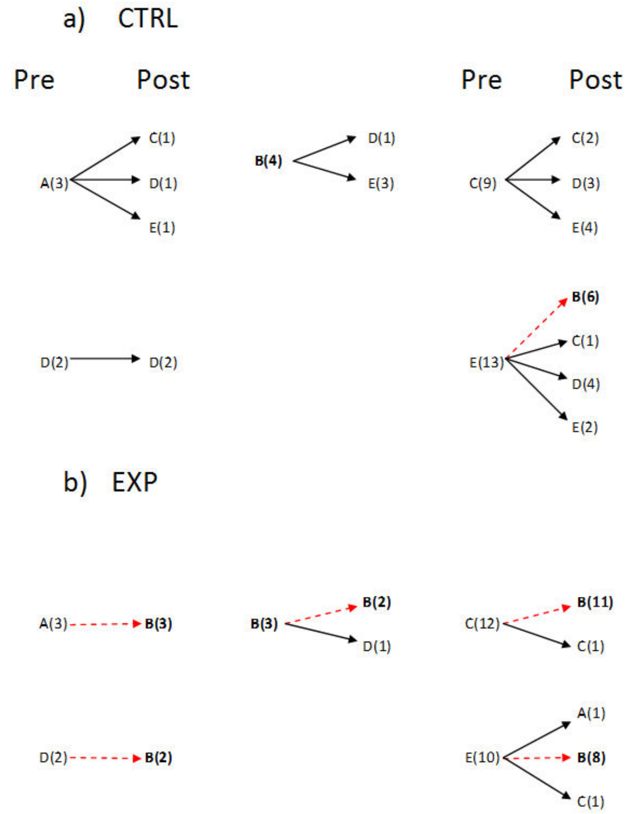

FIGURE 1. Evolution of student's answers to Item 22 of the test DIRECT. For each answer option, the numbers within parenthesis indicate the number of students choosing this option in the Pre (left) and Post (right) tests. The arrows indicate how options selected in Pre test evolved to after instruction (Post). Full lines indicate changes to a wrong option; dashed, red lines indicate evolution to the correct option (B). a) CTRL group, $N = 31$; b) EXP group, $N = 30$.

($II_{\neq}$) in Pre and Post tests. This separation allows us to understand if a given group has one dominant learning obstacle or it is struggling with two or three relevant alternative models, an important difference that can be associated with the efficiency with which the teaching approach handles alternative conceptions.

Following Lasry *et. al.* [1], we define gains and losses as follows:

$$G = IC / (IC + II_= + II_{\neq})$$

$$L = CI / (CC + CI)$$

This particular definition of gain (G) takes into account the number of wrong answers in the pretest that turned to correct in Post test, normalized to all Pre incorrect answers. Similarly, loss (L) is defined as the fraction of Pre correct answers, which turned to wrong answers after instruction. Note that G and L are not normalized to the same total number of cases. Throughout this work, gains and losses correspond to these definitions of G and L.

TABLE I. Average class values of the Pre and Post instruction performances, the five answering pairs and Gains and Losses of conceptual understanding for the CTRL (top) and EXP (bottom) groups. The first two columns indicate the test objective and test items that evaluate that objective. Rows in red show mean values for objectives 1-5 (physical aspects of DC circuits) and Current and Voltage. The last row presents the average values over all Items.

CONTROL										
Objective	Item #	Pre	Post I	CC	IC	CI	$II_=$	$II_{\neq}$	Gain	Loss
1	10, 19, 27	28	30	10	20	18	13	39	28	65
2 and 3	9,18	28	50	10	40	18	11	21	56	6
4	5, 14, 23	14	38	5	32	9	17	37	37	64
5	4, 13, 22	16	44	5	38	11	13	33	45	69
Mean 1-5		21	40	7	32	14	14	33	40	66
Current	8, 17	20	40	15	35	5	13	32	44	25
Potential difference (voltage)	6, 15, 24, 28, 29	15	29	4	25	13	16	37	32	76
Current and Voltage	26	26	29	13	16	13	29	29	22	50
Mean Current & Voltage		18	34	8	26	11	17	35	34	58
Total		20	37	7	30	13	15	34	38	63
EXPERIMENTAL										
Objective	Item #	Pre	Post I	CC	IC	CI	$II_=$	$II_{\neq}$	Gain	Loss
1	10, 19,27	16	66	12	54	3	13	17	64	21
2 and 3	9,18	15	82	12	70	3	7	8	82	22
4	5,14,23	10	62	9	53	1	8	29	59	11
5	4,13,22	11	85	9	76	2	3	10	85	20
Mean 1-5		13	73	10	63	2	8	17	72	19
Current	8,17	8	72	3	68	5	5	18	75	60
Potential difference (Voltage)	6,15,24,28,29	7	51	5	48	4	11	26	57	43
Current and Voltage	26	17	57	10	47	7	3	33	56	40
Mean Current & Voltage		9	57	5	53	5	8	25	61	46
Total		11	66	7	59	4	8	20	67	30

3. Gains and Losses and the type of instruction

Table I shows the course performance in Pre and Post tests, and the relative magnitude of the five answering pairs and gains and loses for each objective and group of objectives of the test DIRECT, a finer subject separation proposed by the test' authors [6].

The CTRL class has a dominant pair, $II_{\neq}$ (34%), which together with those students that kept the same wrong answer ($II_= = 15\%$), shows that almost half the course answered incorrectly both before and after instruction. The second most selected pair is IC (31%), corresponding to those incorrect answers before instruction that changed to correct in the Post test. Situation in the EXP course is very different: the most abundant pair is IC, with about 60% of the students shifting from an incorrect option in the pretest to the correct one after instruction. For this sample, the second largest group corresponds to those selecting a different incorrect answer in both tests ($II_{\neq} = 20\%$).

Table I shows the large difference in gains and losses between the two classes: the EXP class gain ($G_{\text{EXP}} = 0.67$) nearly doubles the CTRL sample ($G_{\text{CRTL}} = 0.38$). Losses due to instruction shows just the opposite situation: $L_{EXP} = 0.30$ and $L_{\text{CTRL}} = 0.63$.

Within this general trend, Table I shows that gains and losses also depend on the particular objective. For instance, gains and losses in both samples seem to be optimized for the combined objectives 1-5 (physical aspects of DC circuits), as compared to the performance in current and potential difference objectives, a relevant information for those teachers that want improve instruction to maximize learning outcomes.

Table I also indicates very low CC pairs (about 8%) in both samples, indicating that solid initial knowledge in both samples was almost null, a reasonable feature for these students without prior instruction on this subject. The other relevant result is that incorrect-incorrect answer pairs do not show a clear difference between equal or different distractors ($II_{\neq} \approx$ 2.3 - 2.5 $II_=$, for this test of 4 distractors per item), indicating no preference of these students for a particular alternative model.

4. Discussion

The aim of this work has been to investigate the influence of the teaching strategy on gains and losses of conceptual knowledge due to instruction, an important feature of the teaching and learning process that has not been studied in detail, as noted by Lasry *et. al.* [1]. These authors showed that gains and losses induced by instruction are a function of previous knowledge, with students of high pre instruction knowledge optimizing the outcome of instruction. Table I shows that, over the different test objectives and group of objectives, the CTRL group obtained relatively low gains and high losses, while the EXP group presented just the opposite situation: high gains and much lower losses. If we use Fig. 1 of Lasry *et. al.* [1] to interpret these values, the EXP sample achieved as a student sample with high pre instruction knowledge (high gain and small loss), while the CTRL performed as students with very low initial knowledge (low gain and high loss).

Therefore, it is readily seem that, using the data analysis proposed by Lasry *et. al.* [1], but for different physics subject, measuring instrument, education system and type of students, our data suggests that the type of instruction could heavily influence gains and losses induced by instruction.

Dependence of gain with after instruction knowledge provides a complementary view of these results. Figure 2 shows

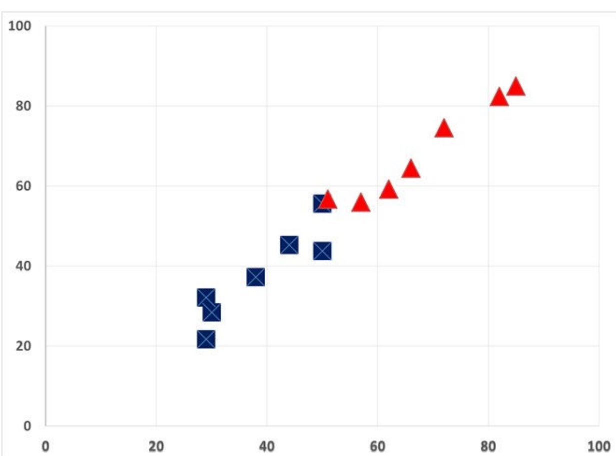

FIGURE 2. Gain G vs Post (% values) for the DIRECT objectives included in Table I. Data correspond to the CTRL (□) and EXP (△) samples.

that, for all DIRECT objectives reported in Table I, gain G and after instruction performance (Post) seem to follow a linear relationship, but with data points clustering in two clearly separated domains: the EXP sample in the high gain region, and the CRTL data in the low gain range, almost without any overlap. Note that although G and Post I have different normalizations, an approximately linear relationship is expected for these particular samples of very low initial knowledge. Complementary, loss L vs Post I data (not shown) also displays a common linear relationship (but of negative slope), with data points of the EXP sample falling in the low loss and high Post instruction region and those of the CTRL group in the high loss and low Post I region. In other words, a teaching strategy that maximize learning outcomes, with high overall post instruction performance, should maximize gains and minimize losses for students samples of very low initial knowledge. Very low pre-instruction conceptual knowledge seems to be case of high school and first year university students of most Latin American countries: science PISA evaluations [7] systematically showed that Latin-American countries perform at the bottom of the international scale. A complementary study [8-10] revealed that incoming university students following science and engineer programs in seven universities of five different countries showed a very low (∼10%) conceptual knowledge of basic physics laws, a situation that should worry not only concerned physics teachers but also educational authorities. In that regard, it is noted that the data analysis method used here is especially suited for large-scale evaluations, and therefore should be of value for obtaining a fast and accurate measure of the efficiency of a given pedagogy to produce high and relevant learning outcomes.

From the instruction point of view, it seems clear that, even adopting a very successful active learning-teaching strategy, more actions could be taken to improve learning outcomes. One straightforward approach is to use complementary active learning-teaching strategies [11] in the different activities of a given course (lectures, problem-solving sessions, labs, etc.), much in the line with the approach proposed by, for instance, The Physics Suite [12] and, at the regional level, by Godoy *et. al.* [13]. As a practical example, in our experiment the two Tutorials on DC circuits could be readily supplemented with the Interactive Lecture Demonstrations [14] "Introduction to DC circuits" and "Series and Parallel Circuits", which provide further learning opportunities using only two extra hours of teaching time.

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