

# Evaluation of Instruction Using the Conceptual Survey of Electricity and Magnetism in Mexico

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**Abstract.** A modified version of the Conceptual Survey of Electricity and Magnetism (CSEM) is regularly administered to students at the beginning of the semester as a pretest and at the end of the semester as a post-test in a large private university in Mexico. About 500 students each semester, from different engineering majors, take electricity and magnetism in the introductory level, divided into sections of 30-40 students so there are several different instructors, both full-time and part-time. We report on the analysis of the CSEM data using concentration analysis for the purpose of evaluation of instruction. The results showed that students' learning varies with respect to instructor and to CSEM concept area. Students have large learning gains in some concept areas but small learning gains in others. Deeper analysis of a concept area showed that some instructors may tend to strengthen some misconceptions that students have. The analysis can be used to give feedback to instructors for the purpose of improving instruction.

**Keywords:** Concept evaluation, concentration analysis, implementation of tutorials, international context.

**PACS:** 01.40.G-

## INTRODUCTION

Multiple-choice questions are a good way to test student knowledge about a topic when the questions are correctly designed. Standard tests usually are made with multiple-choice questions since in this way different student groups can be compared. One of the most common standard tests in the Physics Education Research (PER) community is the Concept Survey of Electricity and Magnetism (CSEM) [1] which is one of the research-based multiple-choice tests founded on the extensive research on student understanding of the main concepts of introductory physics. Because they include as distracters a rather complete taxonomy of alternative conceptions and learning difficulties, they have been shown to be very helpful in determining the degree and prevalence of these difficulties in a particular student population. Testing at the beginning of instruction, for instance, yields important information for planning instruction that is properly suited for the corresponding student population. Systematic results in the field of PER have also shown that tests like these, administered before (pre-test) and after instruction (post-test) provides a valid measurement of the impact of a teaching strategy in the conceptual learning of physics.

A powerful technique called concentration analysis [2] has been developed to measure students' conceptual understanding more deeply than overall scores and the percentage of students who answered a question correctly. In this work, the CSEM is used along with concentration analysis to evaluate the instruction and to give feedback to instructors for the purpose of improving instruction. [3]. The educational strategy implemented during the study was *Tutorials in Introductory Physics* [4].

In the first section the context and general methodology will be described. In the following section we are presenting a detailed description of the analysis technique that we are going to use on the paper. Then will follow the results and discussion of the evaluation of the implementation of an educational strategy. In the last section, we present a study summary.

## METHODOLOGY

Tecnológico de Monterrey is a private university in Monterrey, Mexico, the third largest city in Mexico. The institution has approximately 18,000 undergraduate students of which about 9,000 are in various engineering majors, i.e. mechanical, electrical, civil, etc.

The classes in this institution are taught in a 15 week semesters in a lecture/laboratory format without the discussions sections which are common at many American universities. The lecture meets for three hours per week while the lab meets for two hours at a time six times during the semester.

Each semester approximately 500 students take physics 3, electricity and magnetism, the course chosen for this study. In our institution, students from different engineering majors are divided in sections of 30-40 students with an instructor, who can be a faculty member or a part-time instructor. In the semester the study took place, 12 instructors taught 20 sections of the course as shown in Table 1. Table 1 shows the distribution of sections among instructors.

**Table 1.** Instructors and their instruction

Inst.#	Sections	Position	Instruction
1	2	FM	CLT
2	2	FM	TRD
3	2	FM	CLT
4	1	FM	CLT
5	3	FM	TRD
6	1	FM	CLT
7	2	FM	CLT
8	2	FM	TRD
9	2	PI	TRD
10	1	PI	CLT
11	1	FM	TRD
12	1	FM	CLT

The instructors are numbered from 1 to 12. The sections column is the number of sections of those the instructor was teaching that semester. The position column reads whether the instructor is a faculty member (FM) or part-time instructor (PI). The instruction column indicates whether instructors were using cooperative learning with *Tutorials* (CLT) or traditional teaching methods only (TRD).

Laboratory sections had up to 16 students each. Note that students in a given lab section were not necessarily in the same lecture section.

A modified version of the CSEM [1] was administered to 500 students at the beginning of the semester as a pre-test and at the end of the semester as a post-test. The CSEM modification was the addition of 12 questions to include circuits since this topic is part of our curriculum. The concept areas of the modified version of the CSEM are shown in Table 2.

The modified CSEM pretest was administered in the first lab session (third week). The post-test was administered during the last lab session (15th week). The results were analyzed using concentration analysis as described in the next section.

**Table 2.** Concept areas of the modified CSEM.

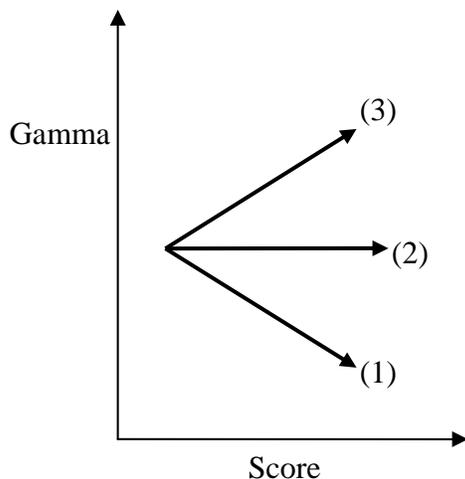
Symbol	Concept areas.
A	Charge distribution on conductors and non-conductor
B	Coulumb's Law
C	Third Law of Newton
D	Superposition of forces and electric fields
E	Force caused by an electric field
F	Work and potential.
G	Induced charge by electric fields
H	Magnetic force
I	Magnetic field by currents
J	Superposition of magnetic fields
K	Faraday's Law
L	Current concept
M	Potential difference concept
N	Equivalent resistance
O	RC circuits

## CONCENTRATION ANALYSIS

Bao and Redish [2] developed a statistical approach to quantify the number of alternative models used in student responses to multiple-choice test, and the degree of relative importance of these alternative models in a given population. In their approach, every item is characterized by two parameters: the fraction of correct answers or score  $S$ , and the concentration factor  $C$ , a number between 0 and 1 that indicates how concentrated are the answers to the different options of each item.  $C$  is 1 when all students choose the same option in the item, and it is zero if the same number of respondents has selected each option.

They propose that student conceptual models can be analyzed by creating a Score-Concentration (S-C) plane and dividing it into nine regions. They defined low ( $S < 0.4$ ), medium ( $0.4 < S < 0.7$ ) and high ( $S > 0.7$ ) performance regions (denoted respectively L, M and H), and low ( $C < 0.2$ ), medium ( $0.2 < C < 0.5$ ) and high ( $C > 0.5$ ) (L, M, H) concentration regions. Locating a particular question in one of the nine (S,C) regions permits one to determine if the students have answered the item according to one, two or more, correct or incorrect models. For instance an item with a score  $S = 0.90$  and a concentration factor  $C = 0.84$ , which therefore falls in the HH (high score, high concentration) region, implies that most students have chosen the correct model, with a small number of wrong answers randomly distributed among the alternative models.

To gain further insight into student alternative (incorrect) models, it is useful to look at the concentrations of the incorrect responses, gamma. A large gamma,  $\Gamma$ , indicates a large concentration of incorrect responses.



**FIGURE 1.** Gamma-score vectors. A particular question can evolve due to instruction in any of the three ways presented. Vector 1 and 2 are good results whereas vector 3 is not a good result.

The nine model-discriminating regions of the  $S-C$  plane have a one to one correspondence with the nine curved regions of the  $S-I$  plane. It can be seen that the ideal outcome of instruction is an item with a high score  $S$  and a low concentration of wrong answers  $I$ , i.e., most students choosing the right answer, while those who do not, pick distractors at random, in such a way that no strong alternative model persist after instruction. Just as an example of the kind of analysis that is possible with this technique Figure 1 shows what can happen with a particular question.

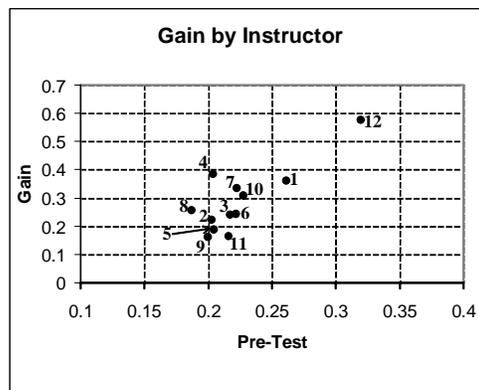
The two ends of the vector represent the pre and post-test results on the question. The Gamma-Score (GS) vector represents the question evolution after instruction. There are three possibilities for a positive gain. Vector 1 or even vector 2 are good results since gamma factor is reduced or maintained the same. This means that no strong alternative model persists after instruction. Vector 3 is not a good result. Even though the score increased, the increase of the gamma factor means that a strong incorrect model persists and has become stronger.

## RESULTS AND DISCUSSION

Figure 2 presents the relative gain versus the score in the CSEM by instructor. Since registration is not random, the differences among pre-tests scores might mean the students choose instructor when they register for class.

Note that the pre-test scores are very low, in the random answer limit. Since the students have not taken Electricity and Magnetism (E&M) in the university

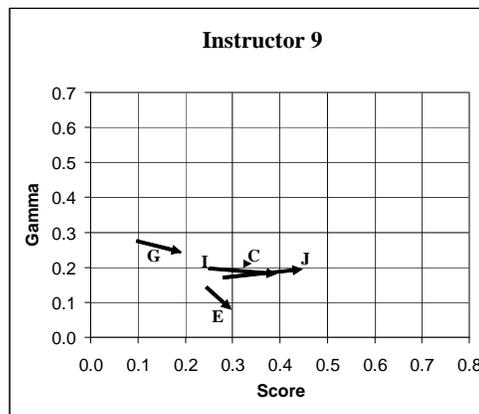
and probably have not taken E&M in high school either, these results are not surprising. Exceptions are sections 1 and 12. These sections have high pretest scores since they are physics majors and honors class.



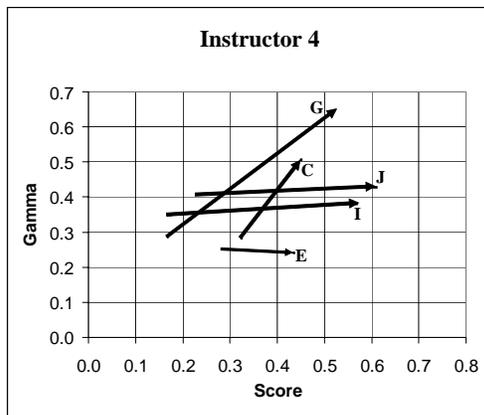
**FIGURE 2.** Relative gain by instructor. Each point represents the average gain of students of an instructor regardless of the sections they were in.

Students of instructors 2, 4, 5 and 9 have similar average pre-test, 0.2. However, according to Figure 2, learning gain is very different, ranging from 0.38 for students of Instructor 4 to 0.16 for those of Instructor 9. It seems that instructor 4's strategy is working better than that of instructor 9.

Figure 3 shows a Gamma-Score graph for Instructor 9. Five concept areas are presented for clarity. The arrows represent how the concept area changed after instruction. Figure 4 shows the same concept areas for Instructor 4. While arrows of Instructor 4 (full time faculty member using *Tutorials*) are long, arrows of Instructor 9 (part time instructor using traditional methods) are short. This means Instructor 4's strategies are promoting more learning than those of Instructor 9.



**FIGURE 3.** Gamma-score graph for Instructor 9. Only five concept areas are drawn for clarity.



**FIGURE 4.** Gamma-score graph for Instructor 4. Only five concept areas are drawn for clarity.

However, more information could be gathered from this analysis. Since a high gamma factor means that, of those students answering incorrectly, most of them have a particular incorrect concept model, it is important that instruction promotes a decrease of gamma, i.e. no strong incorrect model.

We notice that the strong areas of Instructor 4 students are concept areas I and J since there was a good increase on score and gamma did not change a lot, that is, there was learning with no prevalence of incorrect models. However, comparing the concept area C to concept area E and the concept areas I and J to concept area G, the increase of score is similar but the change in gamma is different. On one hand, the results of concept areas E, I and J show that instruction is not promoting incorrect models. On the other hand, results of gamma of areas C and G show that instruction probably is not helping to eradicate incorrect models.

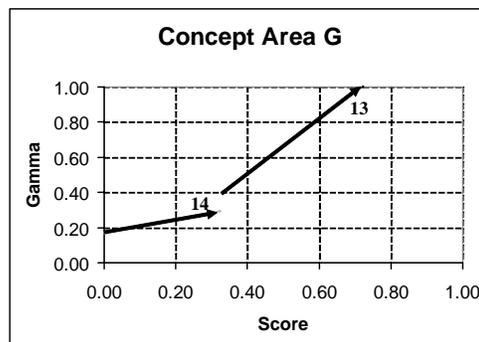
As example, Figure 5 shows a further analysis of concept area G for Instructor 4 which is: *induced charge by electric fields*. This concept area is composed by question 13 and 14 of the CSEM.

Question 13 has an increase of gamma to 1. This means that every student in the post-test who answered incorrectly, chose the same option. Instruction could not correct that misconception: electric field in a metal is only created by external charges. In this case gamma of the concept area G was increased because the gamma of one of the questions increased.

Figure 3 or Figure 4 constitutes (when all concept areas are included) a very good summary of instruction. When this graph comes along with a gamma-score graph of the entire population of students on the course, instructors can see how his/her students performed compare to the whole class.

Gamma-score graphs can be also obtained for specific concept area in which each arrow will

represent one question as it is in Figure 5. This will help the instructor to know what kind of misconceptions his/her students still have after instruction.



**FIGURE 5.** Gamma-score graph of individual questions from concept area G for Instructor 4, questions 13 and 14.

## SUMMARY

A modified version of the CSEM was administered to 500 students in a calculus-based electricity and magnetism course with 12 different instructors as a pretest and post-test analyzing learning gain. Concentration analysis was used in the form of Gamma-Score vectors to assess instruction. These graphs can be used to compare different educational strategies instructors are using in their sections. It can also be used to give feedback to instructors by comparing their results to results of the whole class. In addition, since deeper analysis of GS graphs are able to show strong and weak concept areas, the analysis can be used to give more detailed feedback to instructors for the purpose of improving instruction.

## ACKNOWLEDGMENTS

The authors acknowledge the support received from Tecnológico de Monterrey through grant number CAT140.

## REFERENCES

1. D. P. Maloney, T. L. O'Kuma, C. J. Hieggelke and A. van Heuvelen, Surveying Students' conceptual knowledge of electricity and magnetism, *American Journal of Physics*, **69**, S12-S23 (2001).
2. L. Bao and E. F. Redish, "Phys. Educ. Res." *Am. J. Phys. Suppl.* 69, S45 (2001).
3. H. Alarcon and G. Zavala, *Announcer*, 35, 65 (2005).
4. L. C. McDermott, P. S. Shaffer and PER, *Tutorials in Introductory Physics* 1<sup>st</sup> ed, Prentice Hall, Upper Saddle River, NJ, 2001.