An Analysis of Learning in a Multi-Strategy Active-Learning Course of Electricity and Magnetism for Engineering Students

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ABSTRACT

An electricity and magnetism course for engineering students in the college level is described and its results on students learning are presented. The course is designed to use different research-based active-learning strategies that include not only Tutorials in Introductory Physics from the University of Washington and Peer instruction from Harvard University, but also, other strategies. All strategies are involved with an environment of collaborative learning. The assessment for learning is based on the used of the Concept Test on Electricity and Magnetism modified to include electrical circuits. Results are analyzed by normalized gain using the test as a pretest at the beginning of the course and as a posttest at the end of the course. Analysis of the test in its different concept areas using concentration analysis will be presented. Results showed that this course has a learning compared to honors classes reported in the literature.

Keywords: Conceptual learning, educational strategies, active learning, electricity and magnetism.

1. INTRODUCTION

In the last 25 years there have been great developments in the understanding of how people learn physics in the high school and introductory university levels (McDermott and Redish, 1999). It has been proved repeatedly that to have a meaningful learning, students must voluntarily participate actively to construct their own understanding and that instructors have to take into account all experiences students have been subjected to before coming to the classroom. Many studies of student understanding have been complemented with the development of instructional materials and strategies which promote learning by having students as the center of the learning process.

These materials and strategies are part of what is known as active learning model which is different from the traditional model in that in the old model, the instructor is the deposit of all knowledge that knowledge is poured into the students by good or no so good explanations. Students are the receivers who passively listen to instructors and acquire that knowledge and accumulate it to later present exams.

Many strategies have been proposed in these 25 years (McDermott and Redish, 1999) developing a new field of physics known as Physics Education Research (PER). There have been many reports (Hake, 1998) in which is proved that active learning leaves better conceptual understanding on students than traditional model in similar circumstances (Guidugli et al., 2005).

The objective of this contribution is to generally describe and to present learning results of an introductory electricity and magnetism course which uses different active-learning strategies during the semester. The first section will be dedicated to make explicit the context on what this course is taught. The next section describes in a general way the different instructional strategies that are used in the course. Next, it follows a description of the types of assessment that are used to both construct student's grades and to evaluate conceptual learning. The following section will present the results of the assessment with an analysis of the results. Part of the analysis will be based on the results of a modified version of the multiple-choice test Conceptual Test on Electricity and Magnetism (hereafter m-CSEM), (Maloney et al., 2001), which has been given to course students at the beginning (pretest) and at the end of the course (posttest). In that section we will also present Concentration Analysis (Bao and Redish, 2001), a quantitative technique that has been shown very useful in elucidating the characteristics of the different models with which students respond to scientifically designed multiple choice tests. The main results of this analysis and comparison to other courses are presented in the last part of this contribution, followed by the corresponding discussions.

2. CONTEXT OF THE COURSE

This course is the third introductory physics course for engineering majors. The first course is mostly mechanics; the second is a combination of waves, hydrostatics, hydrodynamics and thermodynamics; and, this course is the typical electricity and magnetism, E&M: electrical interactions, charge, electric field, electric potential, Gauss' Law, current, DC circuits, RC circuits, magnetic interactions, magnetic field, Biot-Savart Law, Ampere's Law, Faraday's Law, Maxwell equations.

The semester consists on 15 weeks and classes are in a three-hour per week basis with a complementary laboratory session that meets in two-hour session six times during the semester. The class is an 8-credit hour class which means students should spend 8 hours per week working for the class including meetings, labs, homework and time to study.

The institution has approximately 600 students who take E&M each semester. Students are divided in 36-student groups. The groups are taught by individual instructors who are either faculty members or part-time lecturers. The particular course of this study is a course offered to students in an international program. This program requires students to have high grade point average from high school, high score on the admission test and knowledge of English at the level of the 550 points in the TOEFL. These requirements make this group to be, in average, better prepared students than the rest of the students.

In general these students have experienced a traditional model of teaching and learning in which the professor transmits knowledge and in which 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 curriculum of the course.

3. DESCRIPTION OF COURSE STRATEGIES

Results in different PER studies in the last 20 years show that students in active-learning courses learn more than students in traditional-learning courses. Hake (1998) presented a study of learning of 6542 students with different learning environments and different initial knowledge in basic mechanics. The results showed that students in active learning environments, i. e. where students participate in the construction of their own knowledge, performed better that those in traditional learning environments no matter what initial level of knowledge they had. The same results have been reproduced in different type of educational systems and with different physics topics (Maloney et al., 2001; Engelhardt and Beichner, 2004; Benegas et al., 2000). These studies make evident the convenience of changing the traditional teaching approach and implement new methodologies. A first step in that direction is this course that pretends to be an active learning course with multiple strategies.

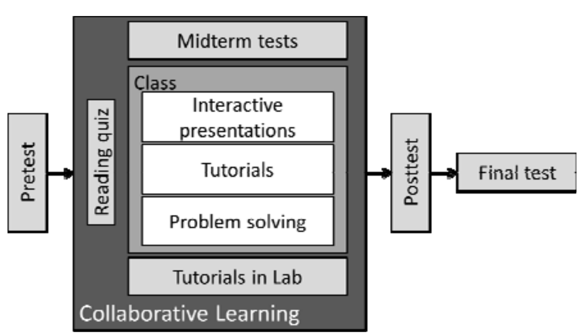

Figure 1: A general overview of the course strategies and assessments tools use in the Electricity and Magnetism course.

Figure 1 presents an overview of the course strategies as well as assessment use in this course. The course has various educational strategies that complement each other. The combination of strategies provokes that most of the time students are in an active learning environment during the class time.

3.1 COLLABORATIVE LEARNING

During the first classes of the semester groups, of four students each, are formed in a randomly way. To make sure no student is in a disadvantage group, it is made sure that no group has a single female (Heller and Heller, 2001). The group formed at this time would be working together for the rest of the semester.

A formal structure of collaborative learning can provide students with positive interactions. Cooperative learning has been proved more productive than competitive or individualistic learning provided that the course structure makes explicit the following conditions: positive interdependence, face-to-face interaction, personal accountability, interpersonal skills and group processing (Johnson and Johnson, 1994).

In the present course positive interdependence is generated explicitly since the common task of each group is not only to understand the conceptual goals of an activity, but also to understand the underlying sequence of scientific reasoning. In that way complementary tasks could readily be assigned to different group members. In second place, roles were assigned to group members, so participants can complement and help with their peers learning.

3.2 ONLINE READING QUIZ

The course technological platform is Blackboard (www.blackboard.com) a web-based portfolio in which students can download course information, homework; can upload completed homework assignments; participate in discussions; and take tests. At the beginning of each topic during the semester, a reading quiz is due. Students are able to take that test three or four days prior to the due date, the initial date of the topic.

3.3 INTERACTIVE LECTURE PRESENTATIONS

The interactive lecture presentations are designed with a modified version of Peer Instruction (Mazur, 1996) and moments of discussion with open questions during the lecture. The modified version of Peer Instruction consists on multiple-choice questions posted on the screen, students individually answer the question; then, instead of talking to a peer next to them as is done in the original version of Peer instruction, students discuss the answer with their own collaborative group until they get into an agreement. Then they are asked again for the answer. In this way, the main advantages of Peer instruction are in effect and collaborative learning will help students to develop some other skills such as positive interdependence.

3.4 TUTORIAL ACTIVITIES

Among the several active learning methodologies that have been developed in the last decades as a practical result of PER, *Tutorials in Introductory Physics* (McDermott et al., 2001) 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 in classroom time, material, and human resources, and c) literature reports (Redish and 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* have been originally developed for the university introductory courses, most of the material can, and have, been used with excellent results at the high school level.

Tutorials in Introductory Physics are a set of paper and pencil activities (helped in a few cases with very simple laboratory equipment). The tutorial cycle (for every theme of basic physics) consists of the Tutorial Pretest, the Tutorial itself, and the Tutorial Homework. The first and the last are individual activities carried out of the classroom, while the Tutorial is worked out in groups of 3 or 4 students during class time. In each Tutorial the students are initially presented with a simple situation, so the first activity can be understood by all students. From there on students' learning is guided by inquiry, confronted sometimes with different alternatives, so conflict between previous and new ideas is provoked and have to 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 the student's ideas about the concepts involved, confronting these ideas with evidence provided by the Tutorial and finally resolving the inconsistencies. The Tutorial Pretests serve mainly the first step, while the Tutorials and Tutorials Homework care for the other two objectives (McDermott et al., 1994).

In some classes (six during the semester), students work with the University of Washington tutorials. Since the classroom were the class is taught does no have a store room nor the store room is close, then tutorials which do not use equipment are done in class.

3.5 PROBLEM SOLVING ACTIVITIES

There are eight times during the semester when the sessions are dedicated to these activities. Problem solving activities are designed to help students to understand how to solve problems by making steps of the solution more explicit and asking them to reflect on what they are doing. The activities were designed with the help of books that are known for their commitment to learning (Arons, 2001; Chabay and Sherwood, 2010).

3.6 LAB SESSIONS

Laboratory sessions consist on *Tutorials* from the University of Washington which use equipment so they cannot be used in the classroom. By the *Tutorials* covered in the classroom and the ones covered in the lab session the whole section of electricity and magnetism in the Tutorials book is implemented.

The lab session consist on laboratory rooms for four teams of four students each. Students enrolled in lab sessions one week after the semester starts and they work with students who are not necessarily with them in the class.

4. ASSESSMENT

The description of the assessment of this course is divided in two groups, the student and the course assessment. In the student assessment, there are a number of tools that are used to assign a grade to students in the course. The course assessment is described in two groups, the hidden curriculum topic which is a goal to the university and the learning of concepts by a published conceptual test.

4.1 STUDENT ASSESSMENT

Reading quizzes described above are graded automatically when students present them online. Homework assignments are assigned in a weekly basis including end of the chapter problems, instructor-designed problems that are related to the problem solving activities and tutorial problems from the homework book included in the Tutorials in Introductory Physics set.

Midterm exams are designed such that both conceptual and quantitative problems are included. There are three midterm exams during the semester and each of them consists on four conceptual multiple-choice questions worth five points each; two tutorial-type problems 20 points worth; and two end-of-the-chapter type of problems 20 points each, adding up to 100 points.

The final exam is a departmental exam designed by the group of instructors who teaches E&M. It consists on 20 multiple-choice questions with half of those concept questions and half quantitative questions.

4.2 COURSE ASSESSMENT

In this course a central objective is the use of formative assessment to investigate conceptual learning and improve instruction. Therefore, it is very important to choose an appropriate evaluation instrument. A great part of the time spent on the class is dedicated to conceptual understanding via Peer Instructions and Tutorials, as strategies to increment student learning; then, it is comprehensible that the Concept Survey on Electricity and Magnetism (Maloney et al., 2001) has been chosen to be this instrument. The CSEM is one of the few scientifically developed multiple-choice tests based on extensive research on student understanding of the main concepts of electricity and magnetism. Since the CSEM includes in each question distractors of a complete taxonomy of alternate conceptions and learning difficulties, it can be used to obtain a picture of the state of students, i.e. a picture of the alternate conceptions and the degree of them in a student population. When administered both as pre and post test, this kind of tests can be used to study the progress of student learning in a particular course.

The CSEM is a 32-item multiple-choice test divided on 11 concept areas of electricity and magnetism with 2 to 6 items each. Each item consists in a question with five choices with one correct answer. The incorrect options include a rather complete taxonomy of alternate conceptions and the more common students' difficulties in electricity and magnetism which makes it ideal to study its results by Concentration Analysis (Bao and Redish, 2001) which will be explained below.

Since the CSEM does not include electric circuits questions and circuits is part of the curriculum, a modified version of the CSEM, m-CSEM, is administered. 12 questions in electric circuits were added to modify the CSEM. The questions were taken from the Electric Circuits Concept Evaluation (Thornton and Sokoloff, nd) but modified to fit the format of the CSEM, i.e. five options on each question.

These questions on circuits add four concepts areas: current, potential difference, equivalent resistance and RC circuits. Table 1 presents the 15 concepts areas of the m-CSEM with corresponding questions on each of them.

Table 1. Concept areas of the modified version of the CSEM. The numbers on the second column represent the number of the question included on each concept area. The first 32 questions are from the CSEM and questions 33 to 44 are the additional questions to test electrical circuits.

Label	Concept area	Questions
A	Charge distributions in conductors and insulators	1, 2, 13
B	Coulomb's Force Law	3, 4, 5
C	Electric field and field superposition	6, 8, 9
D	Force caused by an electric field	10, 11, 12, 15, 19, 20
E	Work, electric potential, field and force	11, 16, 17, 18, 19, 20
F	Induced charge and electric field	13, 14
G	Magnetic force	21, 22, 25, 27, 31
H	Magnetic field caused by a current	23, 24, 26, 28
I	Magnetic field superposition	23, 28
J	Faraday's Law	29, 30, 31, 32
K	Newton's Third Law	4, 5, 7, 24
L	Current	33, 34, 35, 37, 39, 42
M	Potential difference	36, 38, 40, 42
N	Equivalent resistance	34, 37, 41
O	RC circuits	43, 44

An important feature of research-based multiple-choice tests like the m-CSEM is that they contain relevant information about the different models held by a given population, which is reflected by the degree of popularity of the different distractors of each item. Bao and Redish (2001) developed a statistical approach to quantify the number of alternative models used in responding these kind of tests, and the degree of relative importance of these alternative models in a given population. Every test 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.

To gain some further insight in the incorrect models, we note that since the concentration factor *C* is dependent of the score *S*, it is sometimes convenient to characterize each question with the concentration of the incorrect answers, Γ, a number between 0 and 1 that indicates how concentrated are the incorrect answers. The ideal outcome of instruction is an item with a high score S and a low concentration of wrong answers Γ, 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.

5. RESULTS OF STUDENT LEARNING

As a course assessment of student learning, the modified CSEM was administered to all students taking E&M as a pretest at the beginning of the semester and as a posttest at the end of the semester. The data obtained on this test will be analyzed in this section.

The designed of this course was developed during a period of two years. m-CSEM started to be administered in this course in semester one. In that semester, the strategies used included interactive presentations, problem solving activities and those tutorials which do not use equipment. There were some tutorials which were modified to be able to use them with no equipment inside the classroom. They were called tutorial-type activities. In semester 4, Tutorials in lab were implemented for all students. In that semester the remaining of the strategies mentioned above were implemented. The tutorial-type activities were not used anymore since real tutorials were implemented in the lab sessions.

Table 2 shows the results of the m-CSEM from semester 1 to semester 6. Average score and its standard deviation is presented for the pre and the posttest. The last column presents the fraction of the maximum possible gain or intrinsic gain, *g*, defined by Hake (1998) as $g = (\text{Post} - \text{Pre})/(100 - \text{Pre})$. Here Pre and Post indicate overall test course averages.

Table 2. Results of the course. The table presents the average and standard deviation of the pre and posttests of the m-CSEM from different semesters. The normalized gain is in the last column.

		Pre		Post		Gain, *g*
	n	Ave,%	St Dev,%	Ave, %	St Dev, %	
Semester 1	33	20	8	51	18	0.39
Semester 2	24	25	10	49	17	0.32
Semester 3	24	25	9	55	13	0.40
Semester 4	25	27	11	62	18	0.48
Semester 5	32	25	9	56	18	0.41
Semester 6	26	32	16	70	16	0.56

The results show that before semester 4 the course had better results than the average calculus course presented by Maloney et al. (2001) in which the data came from approximately 1000 students. The students in this course start with a lower score in the pretest and they finish with a higher score in the prost-test compared to those of Maloney's study resulting a higher gain. In semester 4 in which the complete design was implemented, results for students taking this course were even better. Students are now performing as well as honors class or majors in Maloney's study.

To gain more information about possible changes in students´ conceptual understanding, it is convenient to consider students' performance by m-CSEM conceptual area. This is simply accomplished by taking the average course performance on those items about a particular area. The averaged pre and posttest results of the students and corresponding normalized gains for each dimension are shown in Table 4 for semester 6.

Table 4. Results of students of instructors by concept area. The definition of each concept area and the questions on the m-CSEM is in table 1.

		Score		
Label	**Concept area**	**Pre %**	**Post %**	***g***
A	Charge distributions in conductors and insulators	44	51	0.13
B	Coulomb's Force Law	58	89	0.74
C	Electric field and field superposition	75	76	0.03
D	Force caused by an electric field	38	59	0.35
E	Work, electric potential, field and force	31	52	0.3
F	Induced charge and electric field	7	33	0.29
G	Magnetic force	15	63	0.57
H	Magnetic field caused by a current	24	83	0.78
I	Magnetic field superposition	31	77	0.66
J	Faraday's Law	16	65	0.58
K	Newton's Third Law	43	87	0.76
L	Current	44	81	0.66
M	Potential difference	59	72	0.31
N	Equivalent resistance	31	80	0.71
O	RC circuits	25	77	0.69

It can be observed in Table 4 that the students in the course performed well in most areas. There are some areas in which this is not true like areas A, C and F. If a normalized gain is lower than 0.3, then it is taken as a low gain as proposed by Hake (1998). Moreover, students are performing in four conceptual areas with a high gain (0.7 or higher defined by Hake).

To obtain more information of students' models, concentration analysis was used by concept area. Each question has a particular score (percentage of students choosing the right answer) and a concentration factor of incorrect answers (defined before, called gamma). A score of a concept area is just an average of the scores of the questions in the area (Table 1). As well, a concentration factor of an area is the average of the concentration factor of the questions in the area. Taking averages in concentration factors not always has a meaningful result since its standard deviation could be very high; however, for qualitative analysis is very useful. If the results are not clear enough, it is always possible to see the data for each question instead of a set of questions.

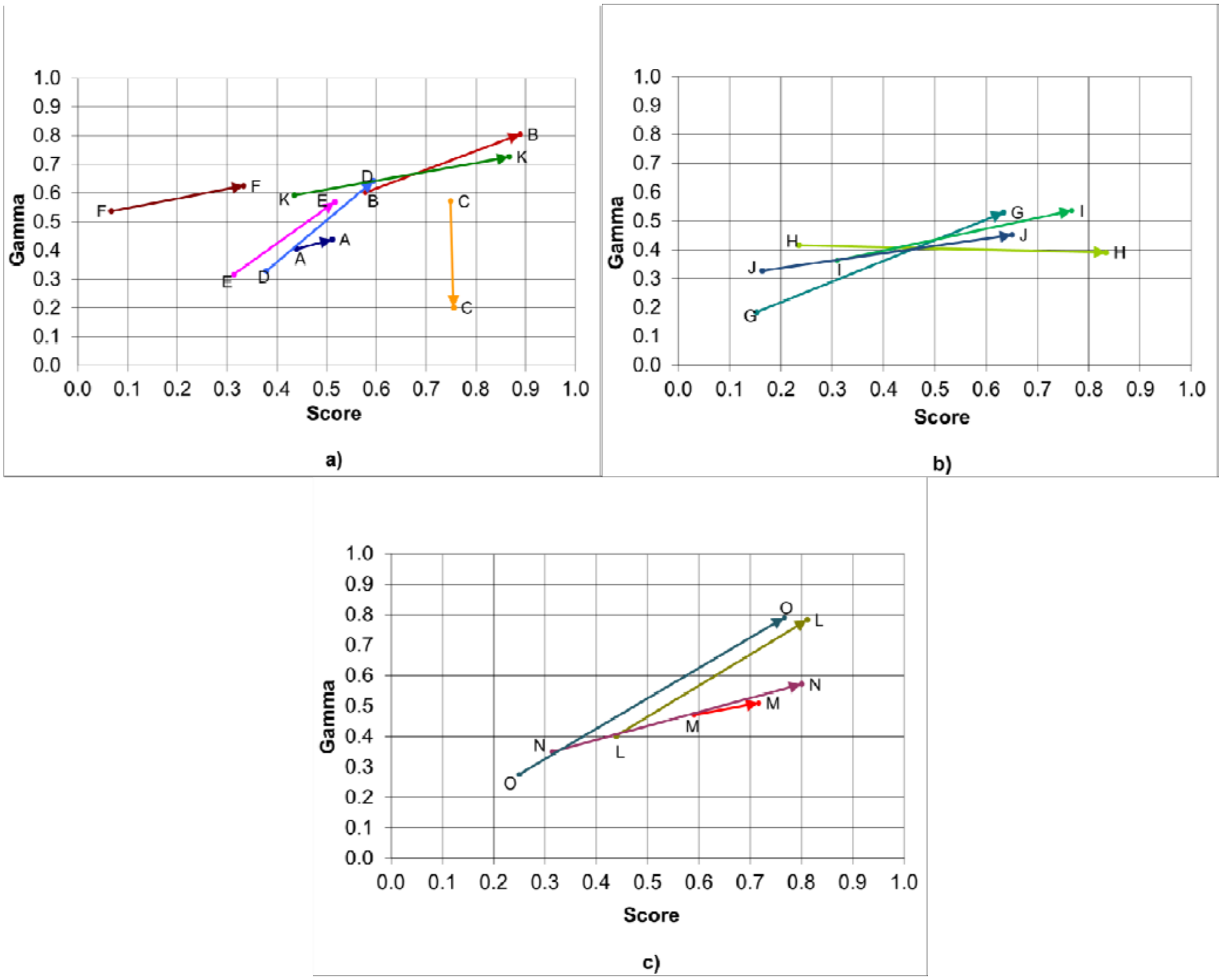

Figure 2: Gamma-score graph by concept area of students in semester 6. Each area is represented by two points joined by an arrow. The initial point is the pretest and the final point is the posttest. Part a) presents the concept areas of electricity, b) presents those of magnetism and c) those of electric circuits.

Figure 2 shows the graphs of gamma, concentration factor of incorrect answers, versus the score of the concept areas of students in semester 6. There are two points for each concept area joined by an arrow. The initial point is the score-gamma in the pretest and the final point is the score-gamma in the posttest. Figure 2 has more information than what is shown in Table 4. In figure 2 it can be observed that results on concept area E and F, work, electric potential, field and force, and induced charge and electric field, respectively, are not good, not only because they had a low gain, but also because there was a substantial increase in gamma in both areas. An increase in gamma means that some students are choosing with more frequency an incorrect model. That could be due to instruction that mistakenly is guiding students to create an incorrect model. On the other hand, concept area C, electric field and field superposition, has practically no gain; however its gamma decreased considerably. This means instruction had no effect on student learning but helped to dissipate incorrect models.

There are some good results too. There are many vectors with a large score increase. The goal is to have long vectors with a slope cero or close to cero. That it will mean that there was a great learning and the incorrect models are not strengthen. In particular concept area H, magnetic field caused by a current, has a great increase in score and a slight decrease in gamma. This is an ideal result in which students have great learning without reinforcing incorrect models. Instruction in this case, guided them to choose correct models and did not wrongly guide them to choose incorrect models.

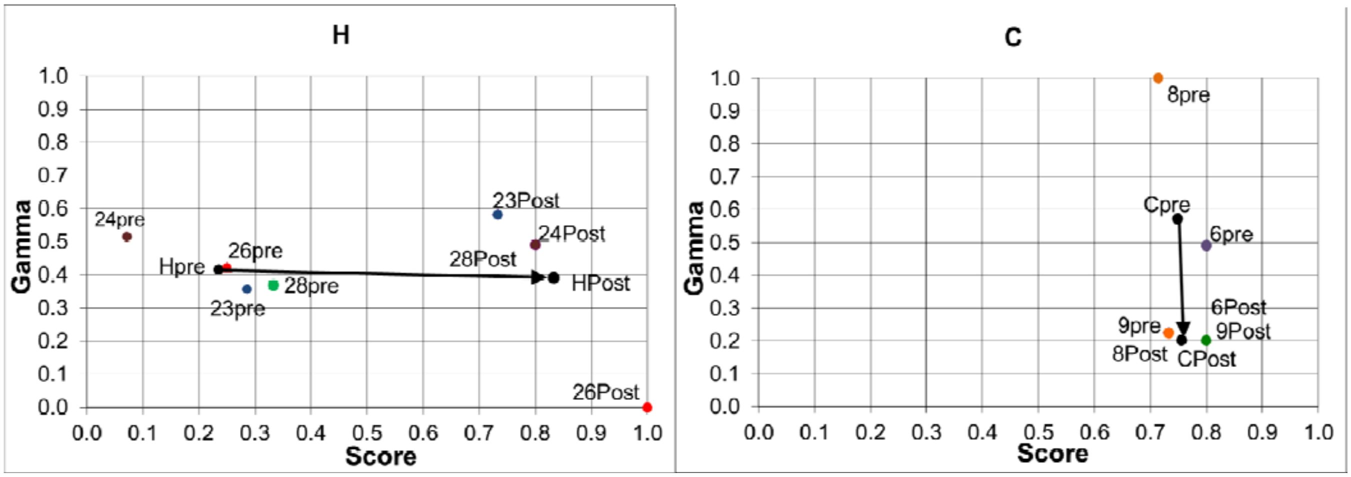

Figure 3. Gamma-score graph of concept area (a) H and (b) C. For each concept area the average and the questions results are plotted.

Figure 3 presents gamma-score graphs of concept areas H and C with their respective questions. Concept area H, magnetic field caused by a current, is composed of four questions, 23, 24, 26 and 28. In all of them there was an increase in score and in none of them there was a significant increase in gamma. This is an example in which the average of scores and gammas has a meaning. In particular the results of question 26 are perfect. In the pretest approximately 25% of students answered that question correctly. The initial gamma was approximately 0.4, meaning that there were students with a strong incorrect model. After instruction, all students answered this question correctly so that no student had an incorrect model.

As stated before, the results of concept area C, electric field and field superposition, are not as bad as they looked. Area C consists on three questions, 6, 8 and 9. Note that for this concept area, students scored high even in the pretest. For each question, there was not a significant increase in score but in all three, there was a decrease in gamma which means incorrect models dissipated. In particular in the pretest, about 71% of students answered question 8 correctly. The value of gamma in this case was one meaning that all incorrect answers are completely concentrated, all students answering this question incorrectly, answered the same incorrect option. On the posttest, 73% of students answered the question correctly (a very small increase); however, the gamma value decreased to approximately 0.23 which means the incorrect model at the beginning of the class was dissipated.

6. CONCLUSION

A multi-strategy course on electricity and magnetism has been described and results on learning have been presented. The course consists on the use of several research-based active learning strategies like Collaborative Learning, Tutorials in Introductory Physics and Peer Instruction and some other active learning strategies like problem-solving activities designed by the author. In particular Tutorials are used in two different ways, given the restrictions of the local environment, some of the Tutorials are implemented in the classroom (those which do not use equipment) and some others are implemented in a separate lab session. Learning was assessed with a standardized test administered before instruction as a pretest and after instruction as a posttest. Analysis of learning gain as a whole and in the different concept areas of the test was presented showing that learning gain was higher than that reported with similar students in the literature. Concentration analysis was used to understand deeper the results of the assessment. There were concept areas in which not only learning gain was obtained, but also, students incorrect models were not strengthen. However, there were concept areas either they have a small learning gain or the increase in the concentration factor of incorrect answers increased meaning that in some way instruction is guiding them to create those incorrect models.

The analysis obtained by the learning gain and the concentration analysis is very useful to assess instruction. With results presented on the tables and graphs in this contribution, the instructor should be able to use it as a feedback to improve instruction.

7. ACKNOWLEDGMENTS

The author acknowledge the support received from Tecnologico de Monterrey through grant number CAT140.

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