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USING SIMULATION PROGRAMS TO ENHANCE LEARNING IN ELECTRICAL CIRCUITS CLASSES

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Abstract *:This paper investigates how the frequently use of two software packages, by college students on Electrical Engineering, can help them in analytical resolution and understanding of the electric circuits concepts. Moreover, between these two programs, we try to identify the best pedagogical tool that can be implemented in the first years of the course and to a possible e-learning. The latest demo versions of both programs, Cadence OrCad 10.0 and EWB Multisim 7.0., were used. The students are submitted to weekly sessions where interactive classes of both programs, manually exercises and computational too are applied. The answers are analyzed and the time of each one of tasks is computed. The computational activities are recorded through a specific program, permitting the evaluation of the student routine in both programs*

Key-words: *PSpice, Multisim, Simulation programs, Electrical circuits, student's profile.*

1. INTRODUCTION

Since the 80´s, many electronic simulators have been developing to solve electric and electronic circuits easier. The Spice, developed by UC Berkeley, is one of the most important programs. Initially created in DOS, the program has been updated and the successively bought for another companies. The latest version is the Cadence OrCad *PSpice* 10.0. With a simplified interface and intuitive commands, the program has been a bedfellow to the professors in Electrical Engineers course. The efficiency in concepts comprehension and in a circuits resolution was proved for many papers [1, 2, 3, 4].

The classes of electrical circuits one is teach in the fourth semester of course, being the first contact of student in a technical discipline. It introduces the classical circuits theory, permitting all comprehension in DC circuits, including resistors, capacitors and inductors, for example. Besides the huge information that should be taught, the time is limited to approach new technologies, like simulators. Therefore, only one-hour presentation of *PSpice* was presented to students in regular course.

Traditionally developing products to electronics area, the programs of EWB (Electronics Workbench) have been a great rival to *PSpice*. Nowadays, the main simulator program on company is the *Multisim*, that have an advanced interface with real components, oscilloscopes, multimeters and many others instruments that approximate it to a real lab bench. With real components, that indicate commercial values, the adaptation of virtual to real is easier. For educational proposes, the program has black boxes to hide components and a menu option to set failures on components, for example, stimulating the student to observe the results on instruments and reach an answer to problem.

Its very difficulty to elaborate extensive classes, involving many subjects, but at the same time doesn't forgetting details. One propose was the use of some credits of this classes in laboratory, with didactic modules, that permits secure experiments of theory. The second option, but important too, was the simulators. Both programs have an intuitive interface with simplified routines, giving to the students an opportunity to explore better all functions available, and a fully understand of the responses of circuits. This paper studies how the intensive use of both programs can improve the traditional methods applied in Electrical Engineer classes.

2. EXPERIMENTAL PROCEDURES FOR THE WORKSHOP

To start the process, 12 students that have been failing at discipline were selected randomly. This group has weekly workshops, with two hours each, to learn both programs. At the beginning, all students were submitted to a psychological survey, created by North Carolina State University [5], to diagnose the learning styles of them. These results indicate if the students were more active or reflective, more sensing or intuitive, more visual or verbal and more sequential or global.

After this first survey, an evaluation of the experience with *PSpice* was applied, since a presentation in the regular classes was offered to the students and some exercises solicited. These workshops were given in a room with 16 computers and each student has your own. The computers have the following configuration:

- Athlon XP 2,0GHz;
- HD 80,0Gb;
- 512Mb RAM;
- CRT Monitor 15",
- Keyboard, Mouse and CD-ROM drive.

All the latest versions of both simulators were installed. To permit a control of all virtual activities, two another programs were installed too: *Cronometer*, that mark the start and the end of each exercise and *Techsmith Camstudio*, that record all the movements in the computer screen, permitting a profound analyses of the most common mistakes performed by students.

FIGURE. A
STUDENTS IN CLASSROOM

FIGURE. B
STUDENTS RUNNING PROPOSED EXERCISE

2.1. QUESTIONS IN THE INITIAL SURVEY

The first survey that was applied tried to understand what happened in the past with each student of group. One of these tests questioned about the quality of class material, like classes, class board, exercises and books. The answer was given through a grade between 1 and 7, knowing "not all satisfied" to grade 1, "somewhat satisfied" to grade 4 and "extremely satisfied" to grade 7. The survey approaches too tests involving fails and the use of simulators since the first presentation that was given in regular classes, questioning, for example, how student was satisfied with *PSpice*, using the same scale to grade. In the same day, one psychological survey was proposed to evaluate the learning style of our group, allowing classes more specifics and with a best return. The survey was created by North Carolina State University, USA, translated to Portuguese and printed for each member of the group. When all tests were solved, these results were transposed to a determined internet site that indicates the tendency of each student. They could be:

- ***Active and reflective learners*:** Active learners tend to retain and understand information best by doing something active with it, discussing or applying it or explaining it to others. Reflective learners prefer to think about it quietly first. Active learners tend to like group work more than reflective learners, who prefer working alone. A balance of the two is desirable. If you always act before reflecting you can jump into things prematurely and get into trouble, while if you spend too much time reflecting you may never get anything done

- ***Sensing and intuitive learners*:** Sensing learners tend to like learning facts, intuitive learners often prefer discovering possibilities and relationships. Sensors often like solving problems by well-established methods and dislike complications and surprises; intuitors like innovation and dislike repetition. Sensors are more likely than intuitors to resent being tested on material that has not been explicitly covered in class.

Sensors tend to be patient with details and good at memorizing facts and doing hands-on (laboratory) work; intuitors may be better at grasping new concepts and are often more comfortable than sensors with abstractions and mathematical formulations.

- ***Visual and verbal learners*:** Visual learners remember best what they see, like pictures, diagrams, flow charts, time lines, films, and demonstrations. Verbal learners get more out of words, like written and spoken explanations. Everyone learns more when information is presented both visually and verbally. In most college classes, very little visual information is presented: students mainly listen to lectures and read material written on chalkboards and in textbooks and handouts. Good learners are capable of processing information presented either visually or verbally

- ***Sequential and global learners*:** Sequential learners tend to gain understanding in linear steps, with each step following logically from the previous one. Global learners tend to learn in large jumps, absorbing material almost randomly without seeing connections, and then suddenly "getting it". Sequential learners tend to follow logical stepwise paths in finding solutions; global learners may be able to solve complex problems quickly or put things together in novel ways once they have grasped the big picture, but they may have difficulty explaining how they did it. Sequential learners may not fully understand the material but they can nevertheless do something with it (like solve the homework problems or pass the test) since the pieces they have absorbed are logically connected. Strongly global learners who lack good sequential thinking abilities, on the other hand, may have serious difficulties until they have the big picture.

2.2. PRESENTATION OF BOTH PROGRAMS AND WORKSHOP ROUTINE

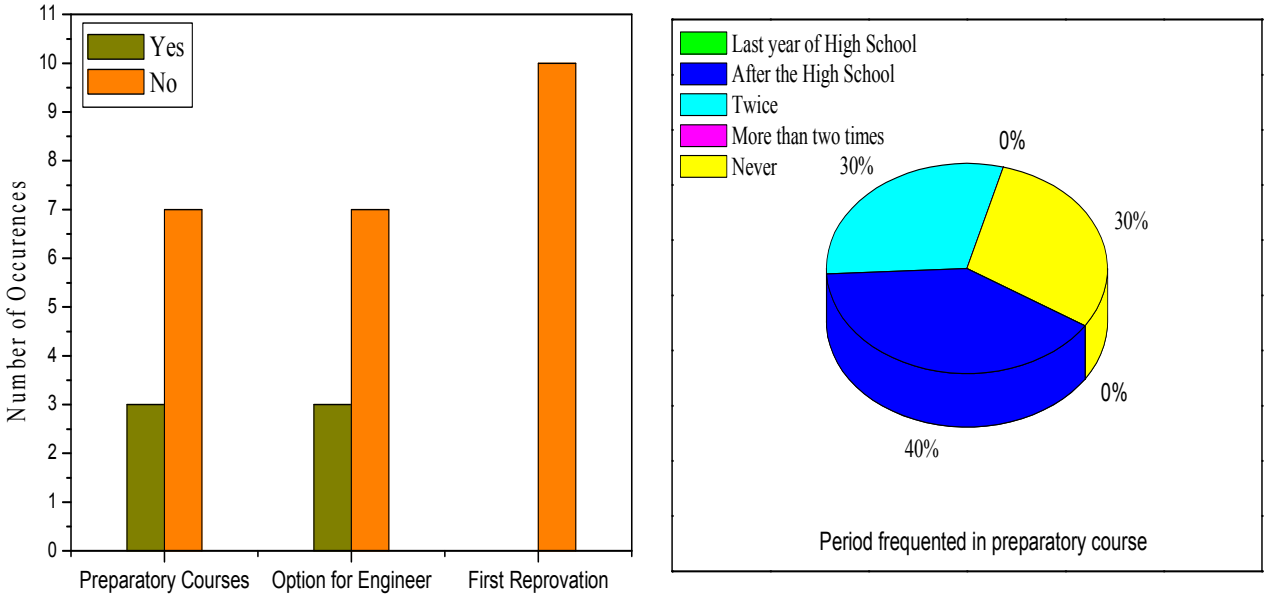
In the first workshop, besides all surveys that were applied, a multimedia lecture of Orcad *PSpice* was given, focusing mainly in routines that could make possible a solution of resistive exercises. The Probe, one program inside *PSpice* that trace all responses of circuit planned in schematic, have no such importance at this moment like the tension, current and power markers, available in schematic. This approach was preferred because the use of markers, in this specific kind of circuit, is easier to learn. One resistive exercise was totally solved in front of students, allowing elucidates all doubts that could arise, and a list of resistive exercises was given to then, picked for many renowned books [6, 7, 8, 9]. These exercises have a difficulty level that increases one by one, reaching in one exercise with more than four loops and dependents sources. Each exercise should be solved by hand in home and bring to the workshop, solved, in the next week. In this workshop, the student was allowed to solve through a computer simulator and to compare the result obtained. All activities in this group has been their electronic activities recorded by *Camstudio* and the time registered by *Cronometer*, while two instructors were available to help students to solve all doubts during the simulation.

When these exercises were completely solved, a third survey was applied to evaluate the knowledge of *PSpice* after lecture, without help. After this, a lecture of *Multisim* was given to then and helping the demonstration, we bring a real digital oscilloscope and a bench multimeter, allowing the comparison between real and virtual. The analyses of resistive circuits in this program have a short notability and we prefer to introduce now the non-linear circuits, with capacitors, inductors and switches. Is more interesting this way because *Multisim* operates with real instruments and the responses are more significant in this type of circuits. Thus, this kind of analysis was approached either to *PSpice*, and the group has the

opportunity to know better-advanced routines in this program and the use of Probe, obtaining better results for each simulation. A new list of eight more complex exercises was selected and the group followed the same method to continue their workshops: solved by hand in home and simulate in university. Since this second lecture including both programs, the students must to solve their exercises in both programs but in the last two weeks of this research, they could choose the simulator that they like more.

3. SURVEY RESULTS ABOUT STUDENT PAST

In the first survey, the prior questions refer about the frequency in preparatory courses and if electrical engineer was the first option in the admittance test in University. Another question was about fails in any disciplines of the course until then. The graph 1a, presented in Figure 1, show that 70% of students frequented preparatory courses and choose electrical engineer for the first option in admittance test. Therefore, 30% of the group studied only because they're entered in a public university and not for option. In this same graph, we can see that 100% of students failed in others disciplines of the course. The graph 1b, presented in Figure 1, shows that 40% of students were admitted in preparatory courses only after the end of high school, entering in a university with 18 years old, approximately. Inside the piece of students that studied in a preparatory course (70%), no one frequented a preparatory course at the same time that studied in the last year of high school. This attitude could forward the admission in university and the entrance in the market job.



(A). **(B)**

FIGURE 1
Student Past in the Course (a) and his Past in Preparatory Courses (b).

3.1. LEARNING STYLE OF THE GROUP AND FIRST SURVEY

Two important results this survey revealed: first, the evaluation of class material and the initial satisfaction with the program *PSpice*, presented through a one-hour presentation in the regular classes of electrical circuits I.

The graph 2a on Figure 2 shows that the students were in someway satisfied with the material present in class. Maybe this value was not better because this discipline have fewer concepts and more reasoning. The preparatory courses in Brazil have a style of class quite different that university. When the students have the contact with a discipline that demand

more insight, personal dedication and less memorization, this model practiced in preparatory courses fails. Has been a challenge to this discipline professor apply exercises, that students claimed for, and don't forget the concepts, that are fundamentals to solve any kind of exercise. Completing this survey, the students were answered about the satisfaction with the *PSpice* program. The majority gives to *PSpice* a five grade indicating a good satisfaction. This result is very interesting because the students have a fewer contact with this program and even that gives to him a good classification, indicating that the intuitive interface of this program really works.

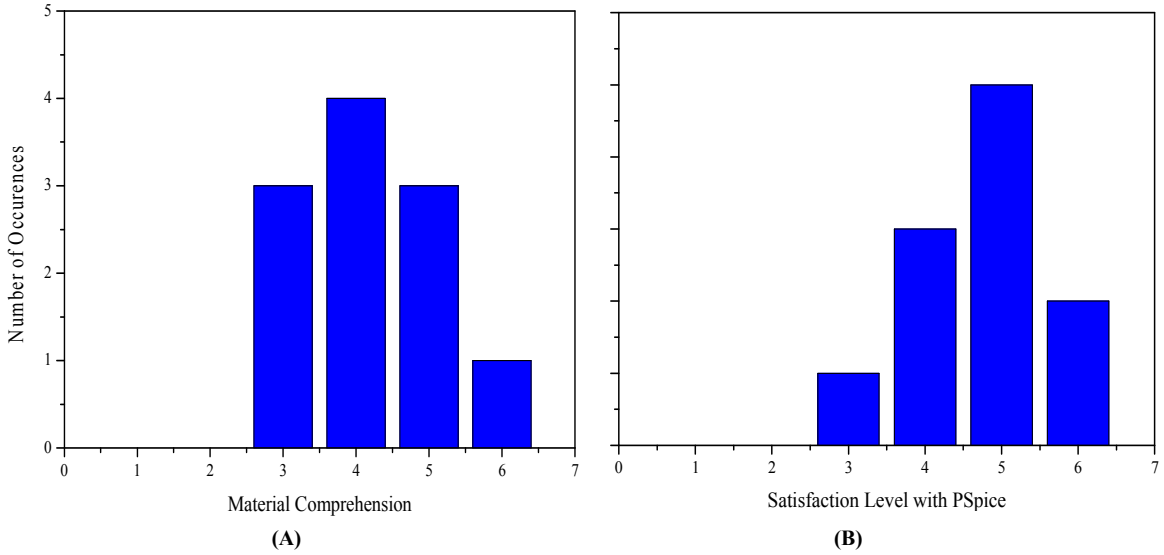


FIGURE 2
CLASS MATERIAL COMPREHENSION (A) AND SATISFACTION WITH PSPICE (B)

The second survey was about the learning style preferences. The graph 3a on Figure 3 shows that the students were more reflective than active, but without intensity, situating the great part in number 3, indicating that the tendency is to be more reflective; but the students have a facility to be active too.

To be a good student, it's important have a little dose of both characteristics and it is happening. The global maximum value is not in the extremes and one local maximum is in the value 3, indicating that our students don't loss their times thinking a lot about something but even not acts unconsciously in the practice: they know think about the problem before act – a mixture of both active and reflective style. At graph 3b on Figure 3, the results indicate that a majority of students have been situated in the visual comprehension area with a great intensity. The learning style method predicted that, not only the students, but everyone prefers learn about something with visual approaches. As we can see, the students prefer more visual classes, with graphs, pictures, flows and not texts and speeches. This parameter guides us to give to the students, in our workshops, classes more interesting of simulators. With a multimedia system, composed by a computer, projector and even real equipments, the information was certainly absorbed in a more pleasant way, as we can see in the next paragraphs.

Continuing in Figure 3, the graph 3c shows an interesting result because we don't have peaks, but bars with low intensity in all axis, and constant in the region of sensing thought. Maybe a characteristic of a course with a lot of calculus and algebra, our students prefer learn with verified methods in opposite to intuitive methods, that demands more abstraction to reach a resolution, but the absence of peaks indicates that these classes can't be extreme in some way. Thus, the classes should have some demonstrations, and innovative thoughts, mixed with the practical theory, like exercises, because if we priories intuition, some details can be lost during an exercise and calculus errors occurred. In the other side, a memorization

of repetitive methods can occur if sensing ways of teach can be used, blocking an innovative and independent thought. In the end, the graph 3(d) shows an incredible peak demonstrating that students prefer learn with a sequential method, even with low intensity (only 3). For our students, is easiest to learn the equation and apply in the problem equally to another that their learn "how to do", implicating in a "memorization method", besides a global and innovative thought desirable to a career so innovative that engineering can be.

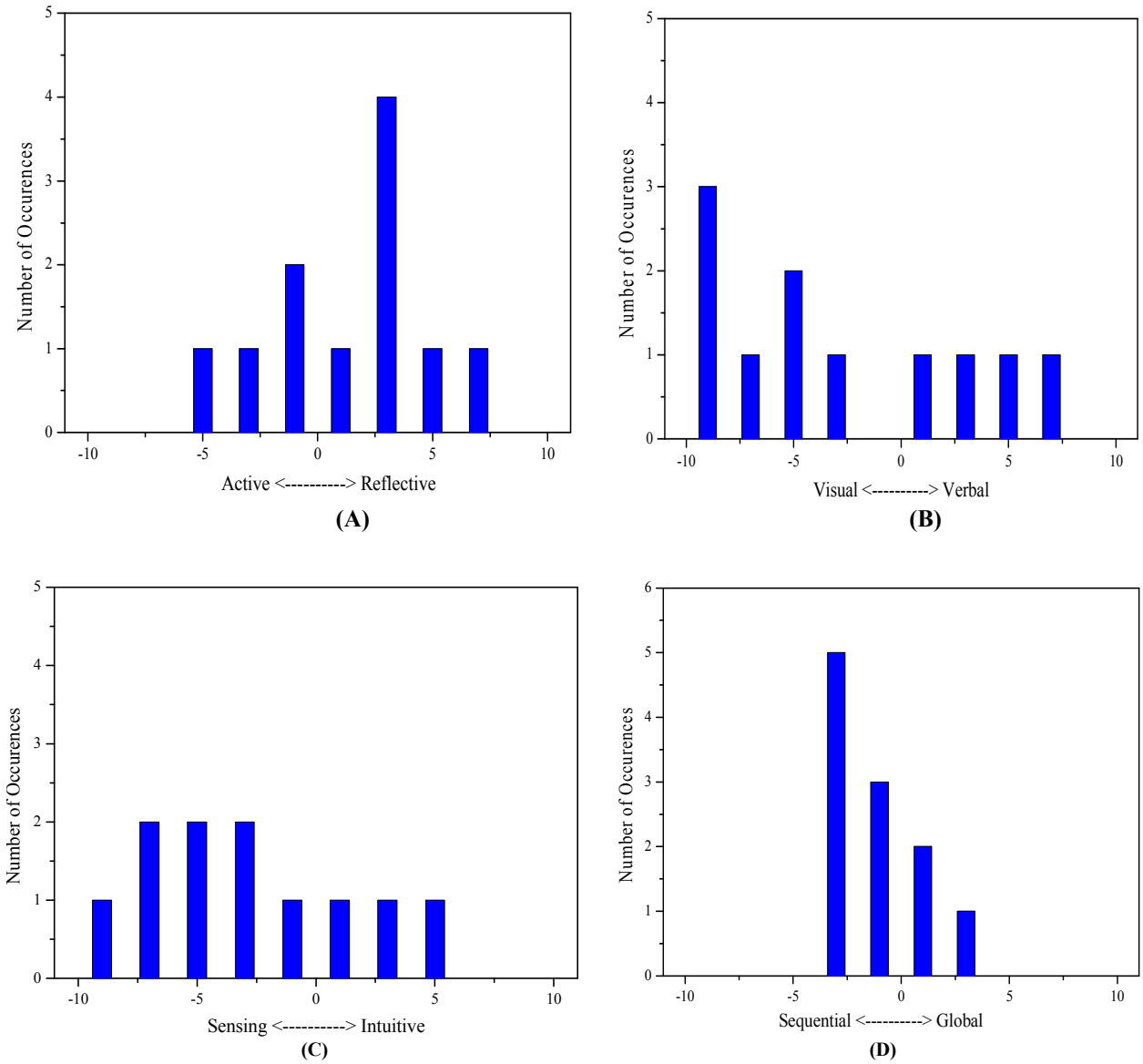


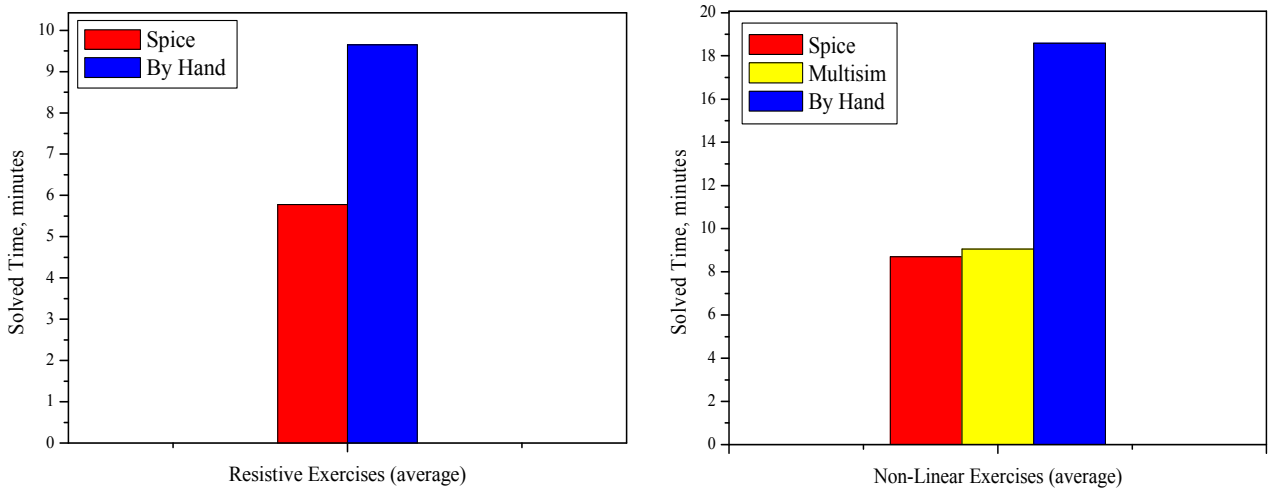
FIGURE 3
STUDENTS LEARNING SCALES (A, B, C, D)

3.2. TIME OF SOLVED EXERCISES

After the first workshop, when the group answered three types of survey (students past, satisfaction with *PSpice* material presented in class and learning style), they been able to solve the exercises proposed and start simulation. Both manually and simulated resolution should be their times registered and, through by hand resolution, they could compare the values obtained in program. The graph 4a on Figure 4, with medium values taken for all resistive

exercises, shows that the difference between by hand resolution and *PSpice* resolution was 40,1%.

When these exercises were solved, a presentation of EWB *Multisim*, and the methods to solve circuits with capacitors, inductors and switches in both programs, was given to the group. A new series of exercises was distributed and, taking the medium values of exercises times, we obtained the graph 4b on Figure 4. With increased level of difficult, the difference between by hand resolution and electronic resolution times reaches 53,21% on *PSpice* and 51,29% on *Multisim*. Certainly, the analysis on transient time difficult by hand resolution and makes the simulator a great tool. It's interesting to notice the little difference on simulators time, on graph 4b, around 3,9%. Thus, when we evaluate the circuit develop in schematic and the way to obtain results both programs are excellent.



(A). **(B)**

FIGURE 4
Time of Resistive Exercises (A) and Exercises with Time Domain Analysis (B).

3.3. PSPICE AND MULTISIM COMPARISON

During all period, the students have the chance to opine about programs, solving troubles and questioning about functions and more detailed routines. After weeks working on that, the programs become a part of their routine of study and they have sufficient knowledge to choose the best program for this propose. To a verdict, we create a new survey with questions involving characteristics of both programs, evaluated with grades starting with 1 (no satisfaction) and ending on 7 (excellent satisfaction). The questions were about the design, components manipulation, way to obtain results, interface and a general opinion, involving all factors that they considered. On Figure 5 we can notice that the values stayed constant for the most of factors, except one. The group prefers *PSpice* to manipulate components through the menu and the keywords in opposite to *Multisim*. Maybe this fact can be explained because the *PSpice* maintain all libraries centered in one window of components and the *Multisim* no, demanding a little more familiarity with the program. As this contact with *Multisim* was the first, the students not have the same interaction that they have with *PSpice*, which was presented first too. Maybe the way adopted by *Multisim* is less preferred to the students.

Here we selected some opinions obtained in the start and the end of workshop. Each student has a code that identifies him.

"I can't compare the concepts with the result obtained in simulator" – PS2 before

"It's easiest learn with Multisim because the similarity with the lab work" – PS2 after

"I don't use a lot (PSpice), so, I not even know the benefits that they can offer to me" – PS4 before

"The Multisim is more similar to reality, but a little harder to make the circuit" - PS4 after

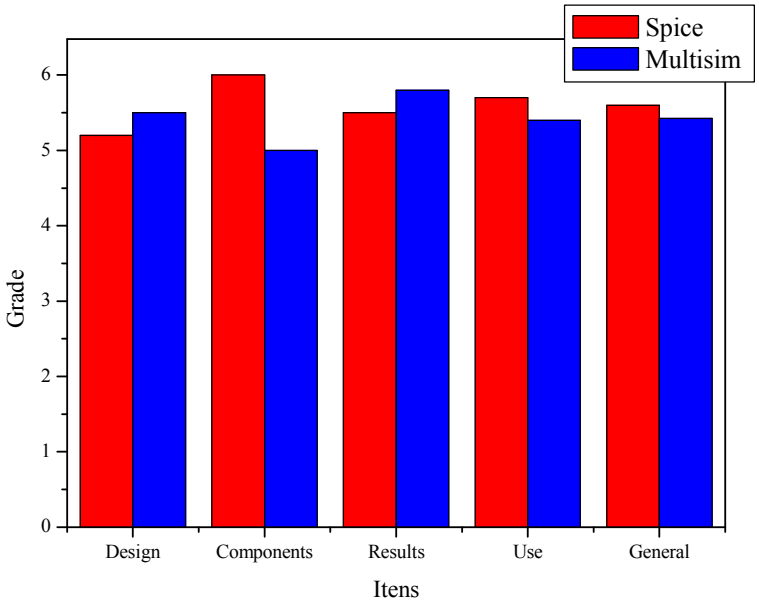


FIGURE 5
INDIVIDUAL GRADES OF EACH RESOURCE IN BOTH PROGRAMS

As we can notice, the students still have some difficulties in the beginning of research with *PSpice*. Maybe this occurred because the short presentation gives to then in the regular classes, without emphasis in operational details of program. However, as showed in graph 7a on Figure 6, the satisfaction with *PSpice* increase after the workshop, indicating a higher comprehension and even a solution of doubts that they having since the first presentation. The major surprise was the choose of *Multisim* by students, as we can see in that phrases above. They never seem before this program and, with a fewer classes in the workshop presenting him, they opted for choose this program to be part of regular classes. Moreover was interesting the grade that they give to *Multisim*, the same of *PSpice* showed on graph 7a of Figure 7, indicating that the design and interface of *Multisim* is, generally, more pleasant for students.

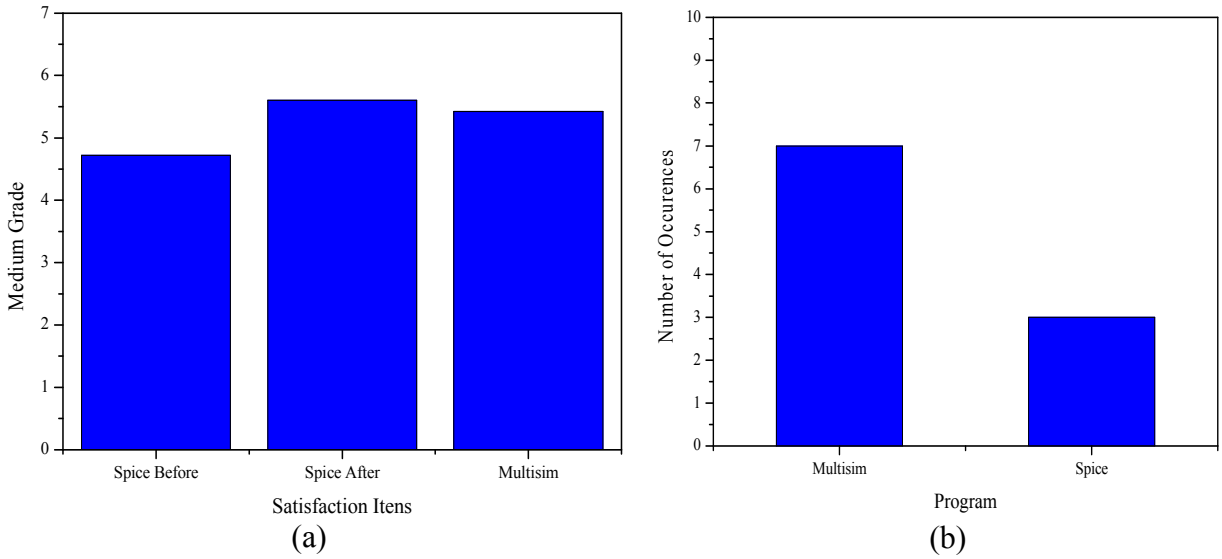


FIGURE 6
FINAL EVOLUTION OF BOTH PROGRAMS

4. CONCLUSIONS

Starting with the data displayed on Figure 2, we can see that the class material classification in situated between somewhat and excellent satisfaction. This discipline classes are made, basically, by discursive analyses, concepts presentation and exercises solving. As showed on Figure 3, the group is partially active and reflective when they need to handle with information, preferring visual information in opposite to texts, learning better with comproved methods and in a way logical and sequential.

The conjuncture of these factors indicates that the classes needed to be more visual, with multimedia approaches for example, to diversify the learning ways, helping the most of students. To assist the active learners, its fundamental introduce the laboratory classes in semester that this discipline happens, supported by simulators that enhances the possibilities of circuits responses. To improve the discursive analyses in classroom, assisting sensitive and sequential learners, all theorems and equations should be demonstrated in a detailed way, giving the idea of each step. Furthermore, an exercise application after the demonstration its fundamental to get the global idea for students. These exercises in classroom could be more interesting if the simulators were used, giving to students the possibility to discuss, in class, changes in components verifying the new responses. Another important question is about the credits that this discipline has, needing to be improved to accept these new ideas.

We could notice a preoccupant fact about student past: 30% of students don't like and not choose the engineer career, only entered in our university because the name and the quality of public school in Brazil. It's widely known that any successfully career need dedication and a taste for what we are doing. These students only have interest in a good university degree. Engineering is an option that needs a lot of personal dedication and ability, since the course is difficulty and has a full classes schedule. The result of this data was showed on graph 1a: 100% of students in group have already been failed in some discipline of the course, before this one, increasing the difficult to follow all another classes whereas you charge past disciplines to new semesters. Another interesting fact was showed on graph 1b, indicating that most part of students prefer ending the high school before entering in a preparatory course. This attitude could be related to an insecurity that students brought from your scholar past, demonstrating a bad apprenticeship. These preparatory courses growth up in Brazil because the quality of public universities in the country and the high level of admittance tests. If these

students could enter a year before in university, would be easier and useful the entered in a market job, permitting to then enjoy more years of active life. Summarizing, it's more easy to students learn all that they need one time and later relearn with a resumed and sequential method, memorizing the way to reaches a solution despising the global comprehension.

When we discuss about the exercises times, graphs 4a and 4b demonstrate that the time of solution through the simulator was lowest than by hand resolution. In resistive circuits (graph 4a) the difference is about 40% and increases much more, about 50%, when exercises with capacitors, inductors and switches were applied (graph 4b). The difference was higher in this case because the difficulty to solve linear equations with many variables. Its easiest draw the circuit in schematic and let the simulator find the solution in opposite to solve many and many steps to find the variables in a Cramer system, for example. *Multisim* and *PSpice* dispended almost the same time to reach a solution, with a difference of 3% favorable to *PSpice*, when these advanced circuits were solved. As discussed in the paragraph above, this discipline has less time to many concepts. The use of simulator in classroom can reduce the time losted when we draw the exercises on board and increase the time to discuss new solutions and ideas. It's hard change the sources and switches to show other responses using only a class board, and the simulators have a great visual appeal making learning more fun and productive.

Evaluating both programs, the Figure 5 shows that *Multisim* was the preference of group in design and the way to obtain results, certainly influenced by the similarity of a laboratory workbench. The *Multisim* has an advantage that the results don't appear as soon the drawing on schematic was finished; only after the operator put the right instrument in circuit (like an oscilloscope, a multimeter, a bode plotter), the results are showed like an extension of laboratory. If the students don't know for what the determined instrument works, and the right way to introduce him in circuit, they couldn't find the solution, obligating then a study and use the theory to apply in practice. However, when the topic is components manipulation, the *PSpice* won, since only with a one click in the right button, all the libraries are accessed and the value changed through a double click in the component. In *Multisim*, the student needs to choose if his want a real component (with a commercial value and tolerance) or a virtual component, that permits the manipulation of values. All this options were accessed by lateral menus indexed by the kind of component (resistor, capacitors, inductor, switches…). Beside all of these complications, in the topic "general" at Figure 5, all simulators have an equal performance.

All these results demonstrate that the students have more and more a sequential intelligence. The demand for a good education in a public school is larger and increases every day in Brazil, imposing to students relearns in a preparatory course all disciplines of high school in a year or even at six months before the admittance test. Due to short time, the professors of these courses tend to explain trivia about subjects and songs to memorize equations in opposite to give detailed demonstrations and formal explanations, promoting the developing of sequential and visual learner. Summarizing, the students has become "a hard drive of equations". As the entrance in university occur, the students suddenly know the real meaning of word "study", since the classes are more detailed and with a lot of little things that should be learned. Summarizing, the students has become "a hard drive of equations". During the workshops, with newest exercises, the students felt difficulties to solve some exercises by hand. Since they not have seeing similar exercises before, they waste a lot of time thinking and trying to adjust their solutions to some other that they knowing. This situation indicates a bad knowledge of concepts and that this student has problems to acquire new knowledges during classes, as we can see on graph 1a.

Other interesting fact that this research comproved was the facility that students have to learn with visual approaches. With a detailed two-hour presentation of *Multisim*, and

exercises practiced in their computers for a couple of weeks, the students could reach all the main routines and even qualify it with a grade similar to *PSpice*, as graph 6a shows, that they knew before this workshop and have already experienced it. Even that, the grade of *PSpice* increases 18% after the workshop comproving this method. The students of the group says that the simulator can help the professor to create unusual situations and show the responses, procedure not indicated to real circuits. This research proposes that our electrical circuits classes have more demonstrations during the concepts presentation, resolution of exercises, laboratory classes and visual presentation of circuits responses. In this last two suggests, the use of electronic simulators is essential, permitting widely options of responses and stimulating the students to opine about, essential to develop a global thought, fundamental to this course. As show in graph 6b, the students like the use of simulators and indicate *Multisim* like an ideal program to help then in discipline.

5. ACKNOWLEDGEMENTS

All students that participate in this research signed a term of agreement which guarantees all privacy that would be needed to restrain the chance of advantages during the workshops. All of then were identified by a code that identifies then during the recorded activities and by hand resolutions. We would like to thank their disposition to be present in all of ours workshops. Our thankfulness to the government of Austria and the city of Villach that contributed to our research. The programs *Cadence OrCad PSpice v.10*, *Electronics Workbench Multisim v.7, CamStudio* e *Cronometer* were installed in the computers of Informatics Technical Service from Unesp, School of Engineer, Bauru Campus, in their demonstration versions. The psychological survey was obtained through professor Felder e Solomon from *North Carolina State University* and its public domain.

6. REFERENCES

[1] SMALLEY, P.: "The effect of software on learning electrical engineering concepts - a case study". 2002. California Polytechnic State University.

[2] TORRES, K.; LOKER, D; WEISSBACH, R.: "Introducing 9-12 grade students to eletrical engineering technology through hands-on laboratory experiences," *31st ASEE/IEEE Frontiers In Education Conference*, vol. 10, 2001, Reno: IEEE, 2001. p. F2E-12 – F2E-16.

[3] ROCKLAND, R.H.: "Utilizing simulation software in a transform analysis course," *29st ASEE/IEEE Frontiers In Education Conference*, vol. 11, 1999, San Juan: IEEE 1999. p. 12c6-1 – 12c6-5.

[4] DOERING, E.R.: "Electronics lab bench in a laptop: using Electronics Workbench to enhance learning in an introductory circuits course," *27st ASEE/IEEE Frontiers In Education Conference*, 1997. IEEE 1997, p. 18 – 21.

[5] FELDER, R.M.; SILVERMAN: L.K "Learning Styles and Teaching Styles in Engineering Education". Engineering Education. v. 78, n. 7, p. 674-681, 1988.

[6] BOYLESTAD, R.L. *Introduction to Circuit Analyses***.** Sao Paulo: Prentice Hall, 2004.

[7] DORF, R.C; SVOBODA, J.A. *Introduction to Electrical Circuits***.** Rio de Janeiro: LTC, 2003.

[8] IRWIN, J.D. *Circuits Analyses in Engineering***.** Sao Paulo: Makron Books, 2000.

[9] NILSSON, J.W; RIEDEL,S. *Electrical Circuits***.** Rio de Janeiro: LTC, 1996.