Evaluation of educational software regarding its suitability to assist the laboratory teaching of electrical circuits

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Abstract:

The present research effort is aimed at investigating of students' perceptions relating to the criteria they themselves would choose in order to select amongst various similar software packages, with the aim of selecting the one most suitable to assist them in their study of electric circuits. For the purpose of the present study, software simulating electrical circuits was deliberately selected. This was precisely because electricity experiments are simple enough to be constructed in a school-lab environment, and are not hampered by friction which (being so difficult to minimise) makes it so hard to take lab-measurements that follow the simple laws of mechanics – often the ones simulated by software aimed for younger students. Considering the electrical circuits, students may find it difficult to correlate the image they see on the bench with the (abstracted) image presented to the drawing of the electrical circuit (all strait lines square corners and symbolic representation of component).

Among educational software that is used as modern tool for the teaching of natural sciences, a distinct and particularly significant category is formed by those packages that closely simulate real laboratory work. The use of software simulations transforms the student into a virtual researcher, by promoting the construction of a model for the problem-at-hand and the study of the effects we get by altering the various physical parameters.

The sample consisted of 101 students from Vocational Schools of all grades and sectors (aged 16 to 20 year old), and in total each student worked for about 9 hours to complete the task of getting acquainted with the packages and then using them constructively before setting on the task of evaluating what they liked in them and what not. The Bessel-corrected standard deviation was calculated for all data points to be presented and the total experimental error was then calculated by combining in the systematic error of the experimental setup. The results are discussed and some interesting conclusions are drawn, which do not only reflect on the particular packages evaluated but on all other simulation software as well, irrespective of topic taught. It is discovered that the most important characteristic of the package favoured by the students concerns the human-machine interface, namely the ability provide a "virtual representation" which is closely simulating the real laboratory situation, while at the same time providing an (interconnected) "abstract-symbolic representation", closely resembling the ones used to be drawn on the blackboard for the study of circuits.

1. Introduction

It has long been suspected amongst educationalists that one of the greatest difficulties students face when trying to draw conclusions from school-science experiments, is to correlate what they see on the laboratory bench with the simplified, idealised, and abstracted drawings (or diagrams) offered as an explanation (additional to adjacent text) in their science textbooks or lab-instruction leaflets. The nature of the problem is complex and it transcends simple explanation of symbols used to depict a resistor or a battery source, for example. Indeed, it may have more elements in common with the difficulty some people have in "reading a map", relating the various symbols with what they see on the road.

2. Previous research efforts in teaching electric circuits

During the past years, a large number of research efforts on Science teaching have been reported concerning electricity. The main research topics seem to be the investigation of students' ideas (or misrepresentations), the study of students' reasoning and comprehension, and the methods proposed for overcoming any intellectual difficulties to conquest scientific thinking[1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22]. One of the most important research results constitutes the ascertainment that the students use alternative models, with the help of which they meditate and try to comprehend electric phenomena and everyday electrical applications. In the present study the focus is on alternative models of simple electric circuits[23,11,24]. For example, before students are taught about electric circuits at school, they believe that in each circuit exist a "source" and a "consumer"[1]. Students usually imagine a "source" as the battery of a circuit and a "consumer" as a lamp. The battery is the current, energy and power provider in the exterior circuit, while the lamp "consumes" them all[1,5,8,10,11,18]. Another usual student perception is that in order for the current to affect the "consumer", it will have to reach this point first, so that it would be possible to interact with it[9,11]. The underlying background of this idea is a mental model of "a something" taking its time to flow from one point to the next in succession, which leads students to believe that the parts of the exterior circuit are successively activated by electricity that starts from the battery and crosses the circuit[11]. This reasoning, which could be characterized as local and successive, has a flaw in explaining the instant changes of current (for example) as soon as one component (like a source or resistor) is changed. The same flawed reasoning leads students to believe that there is no voltage in an open circuit[11]. Finally, it should be mentioned that students in the lower secondary school often use the term "electricity" to describe a multitude of physical concepts such as voltage, current, power etc without distinction[10,25]. This mix-up of concepts is by no means only applicable to electricity, but it also characterises student's thinking at such age. A number of serious studies have been made[17,18,19,26,22] to overcome such problems using traditional (i.e. non-ICT) teaching methods. However, it can be argued that ICT-based teaching methods could stand a better chance in addressing such problems. Their inbuilt ability to simulate various aspects of the circuitry, as well as showing pictures of the circuits while at the same time graphically explaining their operation, could lead to alternative (and more accurate) frameworks in student's mental modelling of circuit's function.

If achieved, this would be in sharp contrast to the results of some previous researchers investigating this area. In the first of them[27] the students used a simple modelling environment simulating simple electric circuits. Research analysis showed that students failed to alter their ideas. In the second work[28] the researchers investigated the extent to which the use of a specific software simulation improves the effectiveness of teaching strategies, specifically designed to achieve conceptual change. The results showed that the simulation does not

promote conceptual changes even though it partially improves students' problem-solving scores. In the third work[29] the authors used a specific open simulation environment as a bridge between traditional class-teaching practices and true laboratory teaching. Their conclusion was that the use of simulation software boosts student's confidence and prompts him/her to complete his/her activity. The final (fourth) study[30], although it also used only a single simulation software, proposed (as a point worthy of further investigation) the comparison between alternative simulation programs in relation to their effectiveness. In their study "…The research was carried out to investigate whether the use of software simulation could help students to improve their comprehension related to meanings such as the flow of current, voltage, resistance, relations between the concepts, and also common symbols that are included in the unit…". That research tried to incorporate software simulation from the beginning of the science course. The main conclusion was that the specific software package used, had a small effect in the learning process, mainly influencing the student's graphical representation ability and their symbolic interpretation skills. On the whole the conclusion was that the use of the particular software simulation did not improve comprehension nor did it improve the use of physical concepts. The level of difficulty in physics reasoning remained similar to the previous three researches. In addition to the aforementioned proposal for further study, the authors also propose further research on:

- The role of the teacher in an ICT-based science teaching class
- The extent to which any ICT-acquired skills could relate and be directly transferable to a lab-related dexterity.

3. Rationale of the present study as to the method and the topic chosen

With all the above in mind, it comes as no surprise, when examining various educational software packages, to find most of them using CAD-like idealised representations of a circuits. This offers little help to those pupils who find it hard to master how the particular circuit (or any circuit for that matter) functions. Such students, even if they can follow the explanation of how the pictorial circuit (made out of lines and symbols) works, fail in repeated attempts to reconstruct such circuits on the lab-bench. Yet it is precisely those students who stand to benefit most from a well designed ICT system aiming to teach electric circuits through simulation – as an addition to regular lab work.

Recognising the nature of the problem, the present research focuses in trying to determine the characteristics of software interface which are most successful to this task. On the contrary to regular practice which focuses on measuring students ideas (and misconceptions) with and without teaching using various software packages, we decided to concentrate on the students' point of view about a number of existing software packages, all competing to assist in teaching the same science topic – electric circuits. The simple reasoning behind such move is that students (particularly when in their teens) are probably quite capable of distinguishing which packages help them along their task and which are not so helpful. Indeed, at this age students can exercise some self-awareness along their arguments, and even describe the evaluation criteria which they think that would be useful for a successful evaluation of such products. In addition, an investigation along these lines would naturally benefit from a lot of additional factors (i.e. differences in student's competence, interest, and prior knowledge) that hamper with systematic errors studies that measure student's understanding as a function of individual packages used as tools to assist learning.

Furthermore, there is a very good reason for using the teaching of electrical circuits as a subject which the packages would aim to teach. In other science topics (e.g. mechanics) software packages can achieve a lot more than what is easily attainable in a school-lab setting (e.g. zero friction, or large and small scale objects, change in gravity as possible on a different planet etc). Electrical circuit software only simulates phenomena easily attainable in a school-lab setting, and any package evaluation would, therefore, have to concentrate on the very subject that forms the very core of our investigation: user interface and the way it guides and assists students in their effort to move from lab-reality to the abstracted (almost transcendental, for some) world of idealised symbolic representation. As a result, we feel that our observations and conclusions have a lot to say about any educational software packages teaching all other topics, but we just chose the present one as the most suitable to yield meaningful conclusions as it is largely unaffected by other parameters who may detract students and affect their understanding.

Among educational software that is used as contemporary tools for teaching Science, particularly significant are those, which simulate accurately laboratory set-ups. The use of such software allows the student to function as a researcher, abstracting any problem into a model and studying the effects of its various parameters.

4. The research

During the present study, students used and evaluated 4 different educational software packages simulating electric circuits.

The investigation started with a pilot-phase involving an informal conversation with some students concerning the suitability of software already used at that time. During the 2nd phase of the investigation, after a short introductory lab-teaching, all students were exposed to the basic operations of a range of educational software (selected by the researchers) all of them competing to be used as lab-tools to teach electric circuits. This lasted for 7-hour per student during which students constructed 5 specific circuits selected by the teacher, same for all the students, so that there could be a comparison of their results. Students, if they had time, could continue designing up to 5 more circuits of their own design.

The 3rd phase involved a person-to-person semi-structured interview (conducted by the researchers) followed. This concentrated on establishing any apparent improvement in their understanding of the scientific topic taught, as well as determining the criteria according to which they would judge the suitability of any specific type of software as being the one best fit for its purpose. The 4th phase involved a further 2 hour (per student) computer-lab work during which students were asked to work on creating and studying simple circuits of their own device, utilising the software already selected by them (whichever that was) as being the most suitable for its purpose. Students' opinions were then collected using a written questionnaire (5th phase), containing both multiple choice and open questions, which corresponded to the evaluation criteria set by the students at the 3rd phase of the investigation. The fixed (multiple choice) criteria along which students evaluated software packages included the following: (a) the facility of use, (b) the pleasantness of its interface as this drawing student's interest and involvement (c) the extent to which it promotes scientific reasoning from the part of the student, (d) the suitability to their age and level of scientific knowledge, (e) the user-friendliness of the environment (f) how appropriate the user interface is in order to achieve its purpose, as the students view it, and (g) user-interest in terms of the originality of interface. When a first reading of students' answers was completed, it was discovered that, while answering the open type questions, some specific terms were used by the students in a way that was dissimilar and incompatible amongst many of them. For this

reason, during a final 6th phase another written open text questionnaire was given, concentrating on clarifying terms used ambiguously during the previous formal questionnaire.

4.1 Objective of the research and educational hypothesis

Our pilot researching effort that is presented in this proposal is aimed at the investigation of students' perceptions for the detection of criteria they place, so that they select among various similar software, they consider as most suitable for the study of subjects related to the unit of electric circuits. The main hypothesis of research was the following: "the students consider as the most suitable software for teaching and learning what gives them at the same time the possibility of using a simulated laboratory as close as possible, to a real laboratory and simultaneously provides with a symbolic environment of work for designing, presentation and analysis of circuits"

4.2 The sample

For this purpose, **101** students TEE (Technical Vocational Schools) of all grades and sectors (aged 16 to 20 year old) used and evaluated the aforementioned four different software packages with the aim understand the workings of the electric circuits, while they used them to design, analyze, and present electric circuits of varying complexity. These vocational students (boys and girls) were keen to learn, as they felt that ICT proficiency is valid as a future professional qualification.

4.3 Research tools

Students' opinions were collected with the help of the aforementioned semi-structured interview and a questionnaire which included both multiple choice and "open type" questions.

4.4 Short description of questionnaire

The aim of the questionnaire was to collect data in regard to sex, age, grade at school, city and region of residence of the students.

The questions of the questionnaire concerned (amongst others) an evaluation of the various software packages, as regards to:

1. The ease of their usage
2. The attraction of students' interest
3. The educational adaptation (-i.e. how well it fits to the level of knowledge, level of interest, and age of students determination of students' knowledge as regards educational software)
4. The user-friendliness of the environment
5. The perceived "originality in the design" of the software packages
6. Relative classification of the software as regards to the (subjective) help they provide for the comprehension of electric circuits function
7. Open type question asking the students' opinion (and justification thereof) as regards to why (if at all) they think that educational software is helpful for the comprehension of the various school subjects,
8. Open type question asking students' preference for the teaching of science using (a) simulated experiments or (b) laboratory experiments or perhaps both. A justification of their choice was also solicited here.

5. Data analysis

Analysis of the overall data collected followed. In addition to the multiple choice questions of the questionnaire, content analysis was performed on the interview data, something that also happened for the open-type questions, which ended-up being classified into broad

categories, for the purpose of being used in a form of quantitative data, and to extract any real information contained in them.

As a general rule, every study (or every measurement, or every evaluation) involves a number of **experimental errors** and, therefore, the present study cannot be an exception. Such errors can be finally folded into a single numerical value (one for every data point), called **measurement errors**. Every experimental point measured is (in general) only valid within the limits of the experimental errors. This is true for every experimental study. While during the data-taking phase of the present experiment an emphasis was paid in minimising biases and avoiding large **systematic errors**, during the data analysis an effort was paid into evaluating these, which after due consideration were set at 3.0% flat, a figure which is comparable with all our statistical errors, and not dominated by them. All relevant statistics were calculated using specially constructed software, interfaced with a popular computational and plotting package. The statistical error was calculated for each and every point of the data-set taken, as this is a function of the sample taken and it varies according to the actual answer given by the students. The **statistical variance** was computed and the **Bessel-corrected standard deviation** was calculated for all data points presented. The **total experimental error** was then calculated by adding in quadrature the systematic with the statistical errors, these two errors being by definition independent.

In some of the questions in the questionnaires, students could choose more than one answer. In these questions it is possible for the sum of the percentages to add-up to something above 100.

6. Results

The results of the analysis of the questionnaires are herein presented, in the form of figures on which the error bars (the meaning of which is explained above) are also denoted.
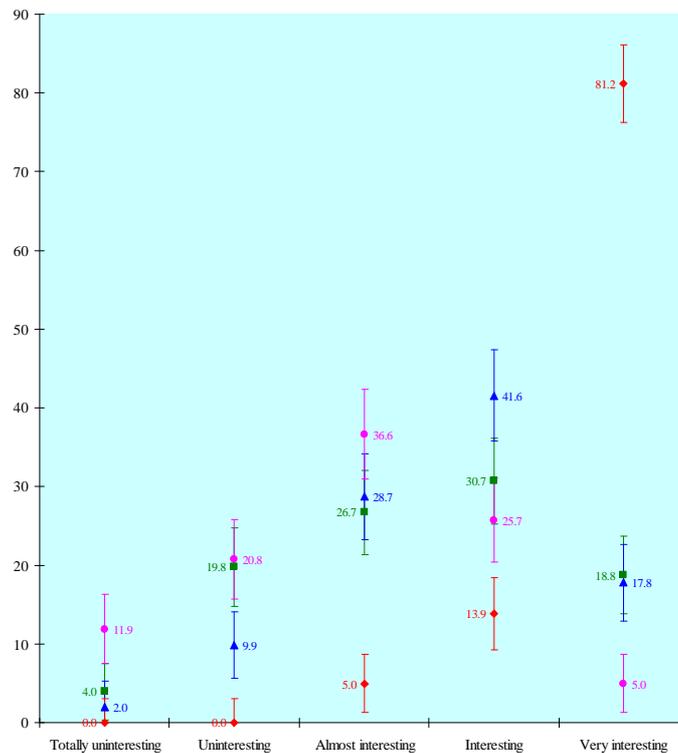
6.1   Question 1
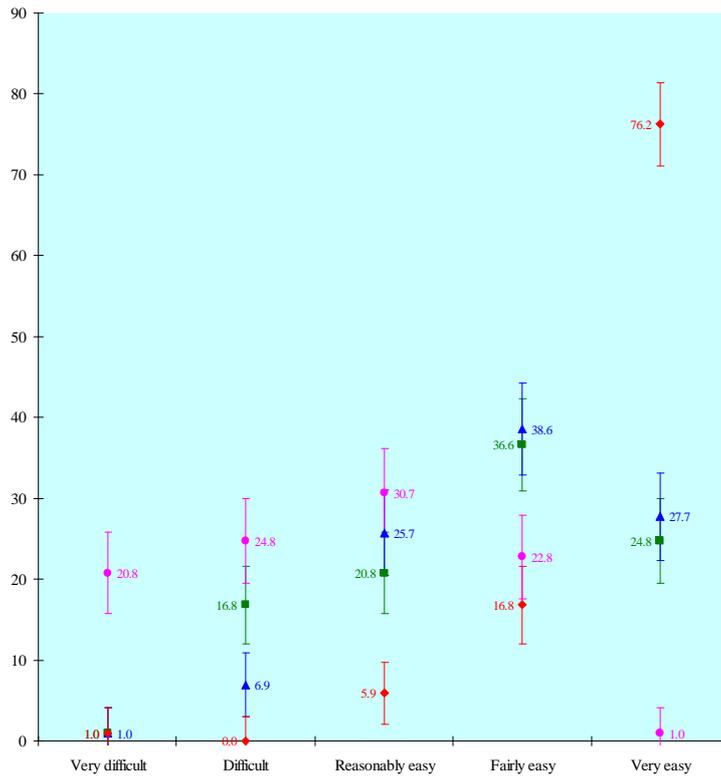
Green squares represent S/W package 1   Red rhomboids represent S/W package 3
Blue triangles represent S/W package 2   Purple circles represent S/W package 4

Figure 1: Ease of Use

It seems that package 3 is clearly rated by the students as being the easiest to use.
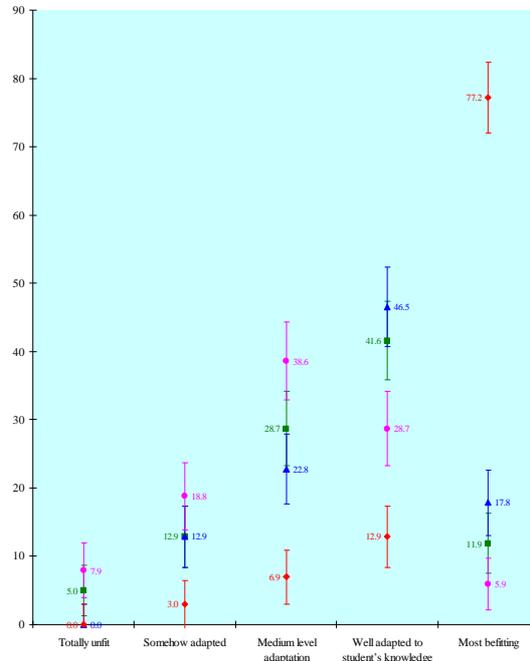
6.2 Question 2

Green squares represent S/W package 1   Red rhomboids represent S/W package 3
Blue triangles represent S/W package 2   Purple circles represent S/W package 4

Figure 2: Attraction of interest

It can be seen that package 3 is also very clearly rated by the students as very interesting to use, and in clear preference to the rest of the others

6.3   Question 3

Green squares represent S/W package 1   Red rhomboids represent S/W package 3
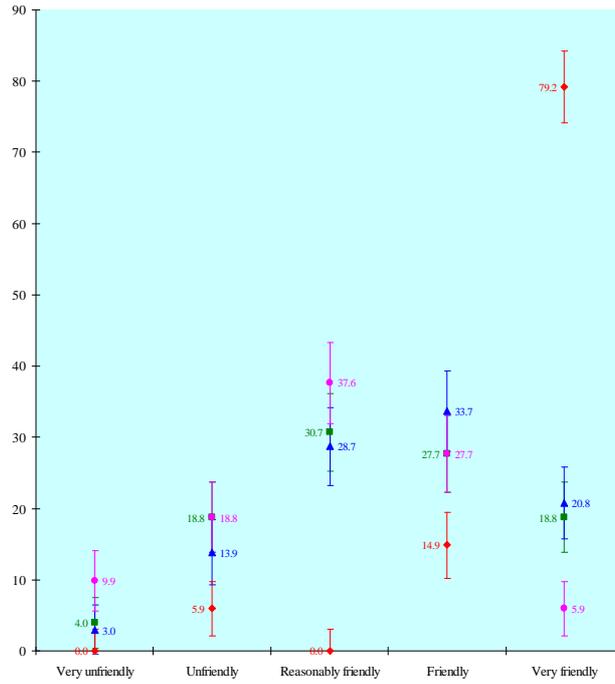Blue triangles represent S/W package 2   Purple circles represent S/W package 4
Figure 3: Educational adaptation (- fitting to the level of knowledge and the age of students)

The present question probes the student's opinion as to if the "depth of content knowledge" offered by the package is appropriate for the particular student's knowledge on the subject as well as his interests. It is by no means certain that an easy to use package offers the depth required by the students, who nay alternatively judge that the knowledge offered by a package goes "too far" for their requirements and interests. It seems here too that package 3 is clearly what the students like most as being the best adapted as regards the content depth.
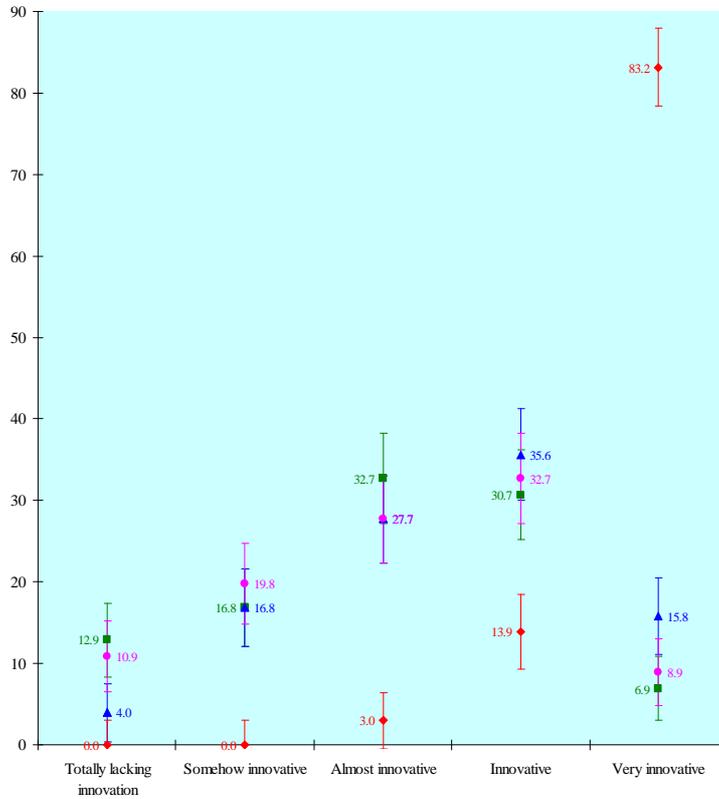
6.4   Question 4

Green squares represent S/W package 1   Red rhomboids represent S/W package 3
Blue triangles represent S/W package 2   Purple circles represent S/W package 4
Figure 4: User friendliness of the environment

We observe that package 3 is judged out of all comparisons as being the friendliest in its use.

6.5 Question 5

Green squares represent S/W package 1   Red rhomboids represent S/W package 3
Blue triangles represent S/W package 2   Purple circles represent S/W package 4
Figure 5: Perceived "originality" – innovative software design

This question probes student's opinion as regards the perceived "originality in the design" of the software packages. The ratings for package 3 are by far superior to any other package tried.

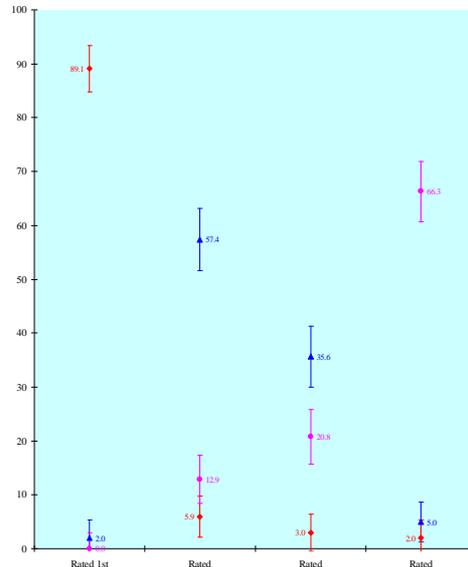### 6.6   Question 6

Green squares represent S/W package 1   Red rhomboids represent S/W package 3
Blue triangles represent S/W package 2   Purple circles represent S/W package 4

Figure 6: Classification of the programs made by the students concerning their appropriateness of the teaching and learning process

In this question we ask the students to place the four packages in ascending order, and thereby express their opinion on how useful they are in general. In other words, how "appropriate" of the four packages are in general in facilitating the student's learning process. We observe that package 3 is judged (out of all comparisons) as being the best for this purpose.
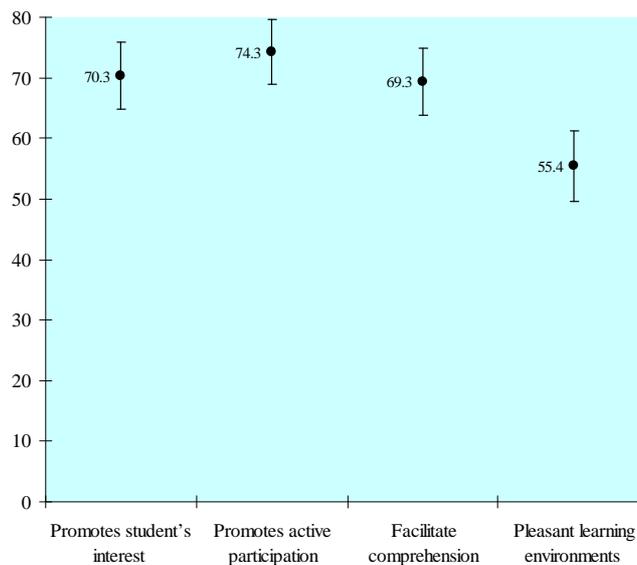
6.7   Question 7

Figure 7: Reasons given by the student as to why (if at all) they think educational software is helpful for their study (open type question, classified by the researchers)

With regards to the open-type question asking the students to justify why (if at all) they think that educational software is helpful for the comprehension of the various school subjects, these answers were categorised by the researchers as falling in the following 4 broad categories. A 70.3 [±5.5] % of the students are of the opinion that it promotes student's interest on the subject taught, while 74.3 [±5.3] % of them believe that it promotes active participation from the part of the students. Please note that the numbers do not add up to 100% as students were free to justify their opinion by using a complex argumentation, in which case their answer fell within more than one category of ours. A further 69.3 [±5.5] % judged that the programs facilitate comprehension for them, and a final 55.4 [±5.8] % think that such programs constitute pleasant instruction environments and make leaning a pleasurable activity.
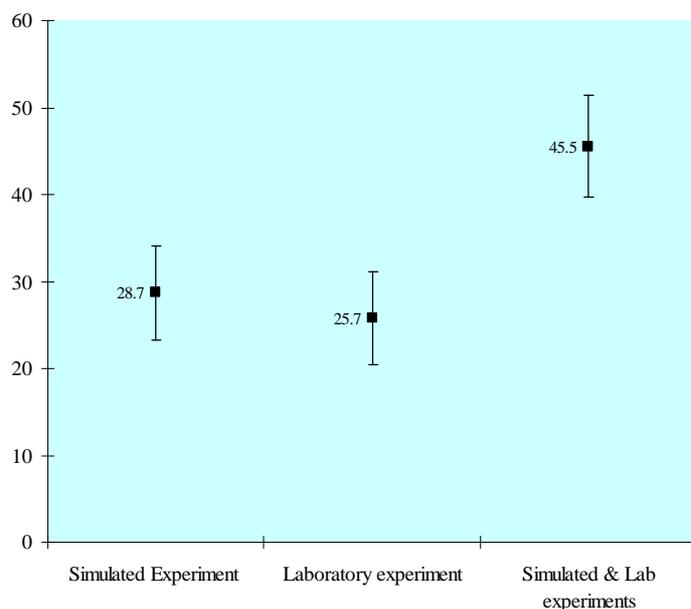
6.8   Question 8

Figure 8: General student preference: Simulated or real lab experiment? (Open type question, classified by the researchers)

As regards the open-type question asking the students judge (and to justify their choice) if they would rather be taught using simulated experiments, or real laboratory experiments at school, or perhaps both, the answers were categorised by the researchers as falling in the following 3 categories. A 28.7 [±5.4] % of the students chose that they would rather be taught using simulation programs, while a 25.7 [±5.3]% still believe that a real laboratory experiment is best for them. Finally, A further 45.5 [±5.8] % of the students considers that the parallel use of laboratory and simulation software as the particular ones they used, contributed to the facilitation of the teaching material, so that it made easier the learning process and in a pleasant environment in the class.

7.   Discussion and conclusions

Educational observation confirms that students really did much better when they utilised package 3, so it was not a matter that they "liked better" this package because it was better to look at, or easier to use. The students were also conscious of this, as it was confirmed by the interviews.

All the above data show that the students overwhelmingly approve package 3 as being their favourite in each and every respect. Incidentally, this package was Edison Ver.4.0, by EdisonLab of DesignSoft Inc. All four packages, nevertheless, claim to help students by simulating (to a certain extent) a real school laboratory and to design and analyse electric circuits. The question arising, therefore, is what aspect (or aspects) of this package is the one that makes it so much better than the rest, in the student's opinion at least. It is the authors' opinion (verified by the extensive interview process) that the answer lies in the human-machine interface. To be more precise, the real advantage is to be found in its dual representation of the electric circuit, one which is more realistic while the other is more abstract, both of which appear on the screen at the same time (see figure 9).
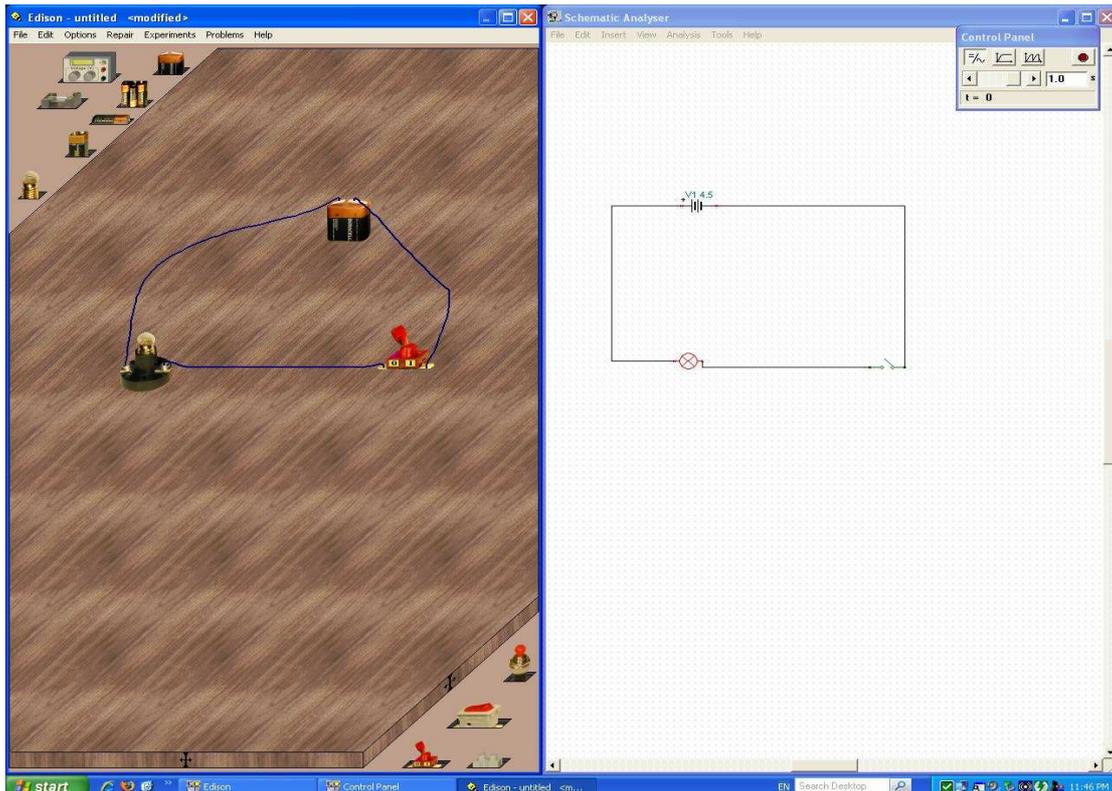

Figure 9: A simple circuit in the working environment of package 3. The double, separated representation can be observed, the left half of which constitutes the realistic "3-D" simulated laboratory, while the right half is the abstracted representation of the circuit. There is also an option to work using only one of the 2 representations (or in both at the same time).

In attempting to analyse the advantage of this much preferred interface we propose the following explanation. Students are faced with the following situation when they are taught electricity: there is:
1. A real-world laboratory, and (and the image the student gets by seeing it – "real-lab representation")
2. A symbolic representation of this construction.

It appears that some students cannot directly "associate" and comprehend symbolic representations of electric circuits, finding that "it doesn't resemble the real world". In a way the situation closely resembles the problem some people seem to have is reading a map, in that they also complain that "the map doesn't look like" the real world outside.

Yet "proper teaching" needs symbolic representation. The advantage of this representation is that it is much simplified in relation to the real-lab representation (in terms of amount of data-

input to the user), hereby facilitating electrical calculations, precisely because it is more abstract, which makes it the first step to the final aim towards the most abstract representation of them all i.e. the electrical equations describing the particular circuit.

The advantage of this "preferred" package seem to be that (when used in parallel with the real lab situation) it plays with 3 levels of representation by creating a "middle level" in which there is some abstraction (for example it is but an image on a 2D screen), but this seems to be sitting in the between of the above 2 levels. Therefore, if we call it to be a "virtual-Lab representation" the student is faced with the following situation:

1. A real-world laboratory
2. A "Virtual lab" representation (trying to visually simulate the real world Lab representation, as realistically as it is technically possible), which really represents the innovative aspect of the computer-user interface, of package 3). Any changes made in this representation are automatically translated (by the package) into the "symbolic" level.
3. A "symbolic" representation (vertical and horizontal lines connecting circuit components, which also appear in a graphic-symbolic way). This is just like the usual one drawn on blackboards and appearing in textbooks). This is presented in the PC screen side-by-side with the Virtual representation and the way it is drawn resembles a simple CAD package. This representation is intimately connected with the Virtual Lab representation, in that these two are always the equivalent to each other –electrically. On the other hand this is a "slave" representation in that any (CAD-style) changes made by the user do not effect any changes to the "master" virtual lab representation.

The advantage of the virtual representation is that it is much more realistic, and it looks much more like the real lab situation. It is therefore much easier for the student to associate with this representation what he has constructed in the school laboratory.

The advantage of the particular simulation package the students preferred is that it not only provides the "virtual representation" to the student, but it also provides an automatic and direct connection between this and the "symbolic representation", ready for the student to see.

Considering that the "virtual lab" representation was absent from the packages used in previous studies, we have reasons to believe that our data can provide a possible explanation to the observations of some aforementioned studies[27,28,29,30], which observed no appreciable educational advantage in the use of simulation software. On the contrary, simulation software with an interface like the one favoured by the students seems to help them transverse from the real world they see in the lab to the abstract world of the circuits as these are represented in their textbooks. The link between the two interfaces of the package (virtual and abstract) seems to be of crucial importance as it guides the uninitiated to the way abstractions are made, in the representation of electric circuits.

The authors believe that the design of all future simulation packages can be much improved by these observations.

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