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Impact of WLABEL exploitation on electricity learning: analysis of the students' conceptual evolution

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Abstract

From studies whose objectives were the diagnostic of students' conceptions and the development of teaching strategies to promote conceptual change, we designed a learning environment (WLABEL – Windows Electricity Laboratory) that aims the promotion of conceptual change in electricity. In this contribution, we briefly present the learning environment. The main purpose of the paper is to describe the qualitative studies carried out to evaluate the impact of WLABEL in students' conceptual development. Since we have used several instruments, special attention is dedicated to the data triangulation carried out and to the analysis processes. In the last section a synthesis of the results is also presented.

Keywords

Learning environment, students' conceptual change, evaluation, electricity, data triangulation

1. Introduction

Students' alternative conceptions and conceptual change have been a main topic in science education research in the last decades (Jenkins, 2001). As referred by Finley et al. (1992) and Pfundt & Duit (2002), in the eighties researchers were interested in the identification and understanding of students' alternative conceptions and in the promotion of conceptual change. More recently, they try to understand the process of conceptual change and the factors that influence it (Chi et al., 1994, Appleton, 1997, Rhöneck et al., 1998). Literature describing the use of ICT to promote and understand conceptual change is sparse (Kearney & Treagust, 2001).

The present contribution is part of a study whose aim was the development of a learning environment (WLABEL – Windows Electricity Laboratory) able to diagnose students' alternative conceptions and to promote conceptual change in electricity (Loureiro & Depover, 1999, and Loureiro, 2002). Our starting point was the assumption that the development of learning environments has to incorporate the results of the educational research, in this case research in science education – electricity. Therefore the project was developed following an iterative model with empirical studies interconnected with development phases. The project was developed in the following phases: a first one, where students' alternative conceptions in electricity were identified; then, teaching strategies were developed and tested; and, finally, the learning environment itself was developed and evaluated.

The evaluation strategies used, that involved students as well as teachers and researchers in educational informatics, indicated that (Loureiro, 2002): students had no problems in manipulating the software and had a very positive opinion about it; the quality of the software is high, since according to the teachers enrolled in the evaluation process it supplies immediate feedback, it helps the student to auto-evaluate what he is doing (without negative effects) and it can help teachers to familiarize themselves with students' alternative conceptions in electricity as well as with strategies to help students to change them.

The impact of the exploitation of the WLABEL learning environment on electricity learning was evaluated in the case of seven students using a qualitative methodology. In this paper, after a brief description of the learning environment, we describe the methodological options of the study. Since we used several instruments, special attention is dedicated to the description and triangulation of the data and to the analysis process. In the last sections, we also present a synthesis of the results of the impact of WLABEL on students' electricity learning inferred from the triangulation of the data obtained when the students were using the learning environment and from the application of a diagnostic test and the students' logs at the beginning and at the end of the study, presented elsewhere (Loureiro & Depover, 2005).

2. WLABEL description

As already mentioned the objective of WLABEL is to promote conceptual change. The environment differs from existing educational software with similar objectives (for example, Brna, 1988, Boohan, 1992 and 1993, Grob et al., 1993, Chang et al., 1998, Jaakkola and Nurmi, 2004, Jaakkola et al., 2005) by integrating the diagnostic of the students' alternative conceptions, their test, and the help function that supports students in changing their alternative conceptions. In order to offer these potentialities, we developed a tool that can be used in the different modes that are described in the subsequent paragraphs. The software interface is presented in figure 1.

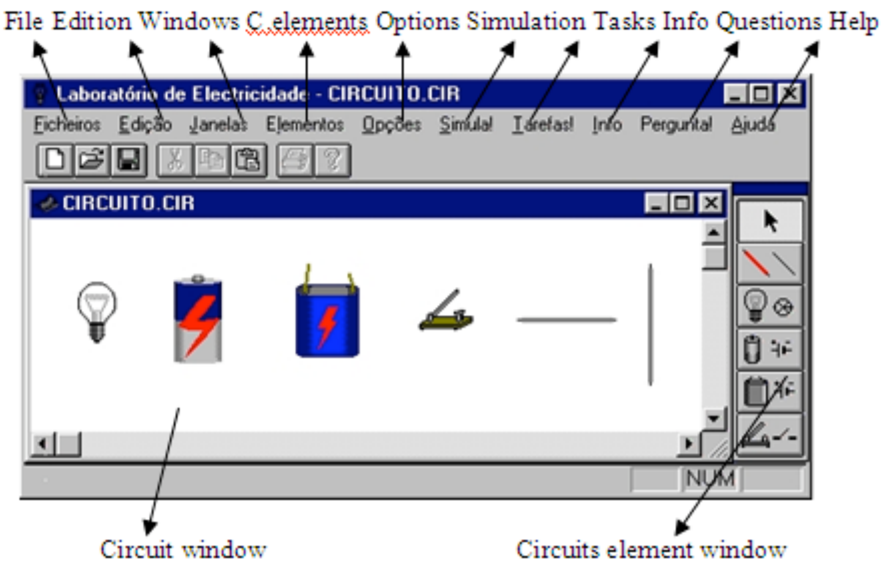
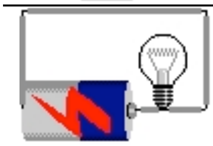


***Figure 1*:** WLABEL Interface

The working modes of WLABEL are the following.

- *Draw tool*: allows students to draw electric circuits in a graphic interface. The drawings can be saved on disc. It is possible to diagnose students' conceptions from those circuits.
- *Simulation tool*: the program can be used to simulate electric circuits, exposing students to the consequences of the use of their conceptions, thus provoking cognitive conflict. Two types of feedback were implemented: one is to light the bulbs correctly connected and to blow-up those whose characteristics where not respected (making a noise and breaking the bulb filament) and the other is to give some general comments about the circuit (table 1). If the student indicates that a given task is finished, the software tells him if the circuit corresponds to that task and is correctly assembled.
- *Reactive tool*: in this mode, the task being done must be indicated. Given the student's characteristics and the circuit that he sketched the program reacts to students' manipulations by presenting one of five different tables. Each table corresponds to a different electricity model and has a set of sentences with the underlying ideas of the model. From those tables, the student selects the sentences that match with his own ideas. Once the student finishes this selection and if any deviation between the student's conceptions and the scientific ones is observed, the software originates a series of questions and hints (the help) intended to help the student to acquire conceptions closer to the scientific ones.

Table 1 - general comments and the help that the software would show if a student drew the circuits presented in the table when trying to solve the first task: to draw a circuit to light up a bulb.

Circuit	General comment and help
	**General comment** – The circuit is opened! There are not any conductive paths between the battery terminals. **Help** – The circuit has problems with the number of terminals of the elements! You connected it like this perhaps because you see electric appliances connected by one simple cable. However, in that cable there is more than one conductor. Why is that so?
	**General comment** – The battery is short-circuited! A conductor wire connects its terminals. In this situation, the battery will go flat. **Help** – The circuit has problems with the number of terminals of the elements! If the battery has two terminals, wouldn't the bulb have to have also two terminals?
	**General comment** – The circuit corresponds to the task. ***Help*** (in this case, according to the sentences the students has chosen, three different feedbacks are presented) *Circuit draw* – The circuit that you draw indicates that you already know how to connect the circuit elements. Could you do the same task drawing another circuit? *Source function* – We agree, the battery gives energy to the circuit. How can we know if the battery has energy? What is the meaning of the "volts" indicated in the battery? *Conductor wire function* – Using a more scientific vocabulary, we say that the electric energy is transferred instead of transported.

Information about the students' progression are accessible from the menu « Info », option « History ». Whenever the students use the environment in the reactive mode, the history gives access to a representation of the circuits designed by the student, the conceptions and the electricity model attributed to the students by the software and also the help presented to the students.

3. Evaluation of the impact of WLABEL exploitation on students conceptual development: methodological considerations

The objective of the study was twofold: to determine the impact of WLABEL exploitation in the conceptual evolution of the enrolled students and its integration into the strategies for electricity teaching that we propose (Loureiro, 1993). The questions we pursued in this study were: What is the effect of the WLABEL use on the students' alternative conceptions? Do students progress in their basic electricity learning? How do they progress? What does it happens in the conceptual change process of those students? What are the factors that influence this process?

To determine the quality of the integration of WLABEL into the strategies for electricity teaching that we proposed (Loureiro, 1993), we also had to verify if the learning objectives of those strategies were attained or not, i.e., if the WLABEL exploitation: contributes to the use of reasoning using potential difference; prevents the introduction of alternative conceptions such as "the battery is a constant current supplier" or those concerning the relation between the concepts electric current and potential difference; and facilitates the discrimination between the concepts of energy and electric current.

Several authors pretend that electric circuits and electricity concepts ought to be introduced simultaneously and electric circuits should be presented as causal systems where there is energy transfer (Härtel, 1982, Closset, 1983, Loureiro, 1993). This means that electricity concepts, which are frequently introduced separately and sequentially, should be introduced to help students to understand the electric circuit behaviour and simultaneously with the study of the electric circuit behaviour itself. Like Lee & Law (2001) pointed out students reasoning have to be guided to focus on voltage (potential difference) rather than on electric current for the development of appropriate conceptions in electricity. Accordingly, the concepts to be worked out during the activities were those of electric circuit, energy transfer and its relations with voltage changes. The main questions to be raised by a teaching sequence should then be: Q1. What is necessary to transfer energy in a circuit? Q2. Why and how does it happen? Q3. How can we change it?

The study undertaken to determine the impact of WLABEL exploitation in students' conceptual change was qualitative in nature and involved seven boys, 12-13 years old. They followed optional activities, which included the work with WLABEL (~1:30 h per day), during two weeks at the end of the school year. This option permitted us to work with the students without timetable constrains and during a relatively long period (between 13.5 and 22.5 hours). The number of computers per student and the low level of teachers' preparation to work with computers (Paiva, 2002, and Moreira et al., 2004) contributed also to that methodological option. Concerning the evaluation, as Harvey (1999) pointed out, it may be more correct to test new informatics' resources in a "laboratory" set rather than with students submitted to formal evaluation as would be the case if the study were carried out in a formal classroom.

The first morning was kept to explain to the students the objectives of the sessions and to guarantee their anonymity in the future presentations of the results. Then the WLABEL functioning was described and the students were given the opportunity to manipulate it. The diagnosis of students' alternative conceptions was done with the software and with a questionnaire. As explained above, with the software, the student selects the sentences that match with their own ideas. Examples of those sentences are: the energy supplied by a source (battery) is always the same; the conducting wires transport the energy to the receiver (bulb); before and after the receiver (bulb) the current has not the same value. In the questionnaire, students had to use their conceptions in various contexts. For example, they had to indicate the differences between the energy transferred, the potential difference applied and the current circulating in two different electrical appliances and explain their answers. At the end of the morning the students also responded to one part of the opinion survey related with their familiarity with ICT and their attitudes towards computers.

In the working sessions with WLABEL the students did the tasks foreseen in WLABEL (table 3) divided in four working cycles (two tasks per cycle). Worksheets oriented the activities. In these sheets we included the questions (Q1 to Q3) presented above. The last one was worked during the last two cycles. After answering the question, students were asked to draw their first attempt to do the tasks and to explain their functioning. Following that, they could freely use the software to do the tasks. At the end, they should write the conclusions of the working cycle, answering the questions in the beginning of the worksheets. All the students did the same tasks at their own pace.

Table 2: Tasks foreseen in WLABEL.

Cycle/Question	Task	Description
C1/Q1	T1	Draw an electric circuit to light a bulb
	T2	Draw an electric circuit with a bulb controlled by a switch
C2/Q2	T3	Change the brightness of the bulb assembled in a simple circuit without changing the bulb
	T4	Change the brightness of the bulb assembled in a simple circuit without changing the battery
C3/Q3	T5	Draw an electric circuit with two bulbs with the same brightness
	T6	Draw an electric circuit with two bulbs with different brightness
C4/Q3	T7	Draw the electric circuit of a Christmas Tree controlled by a switch
	T8	Draw the electric circuit of a dolls house with three different lamps that can be controlled independently and switched-off at the same time

The didactic strategies used in the working cycle were similar to those used in the classroom when we evaluated our approach to electricity teaching (Loureiro, 1993): diagnosis of students' alternative conceptions (from the circuits drawn in the sheets and with WLABEL and from the sentences chosen with the software); students confrontation with their own ideas (from the results of the circuits simulation and the feedback presented by the software); restructuring of ideas (with the help presented by the software); application of new ideas (structured interviews); and reflection about the learning process (structured interviews).

In the last day of activities the students answered the diagnostic questionnaire again and the questions of the opinion survey related with the WLABEL use.

4. Students' conceptual evolution

In the following paragraphs and since in this contribution we can't describe the analysis process for all the learning cycles mentioned in the previous section, we illustrate it for one of them (the third one). Later, we present a summary of the results of the triangulation of the data obtained in the four learning cycles. In the last section of this paper we present some of the conclusions of the study.

4.1. Description and triangulation of the data

For each cycle we described and analysed how students have done the tasks foreseen in the environment (two per cycle), and also the students' reasoning and triangulated the results. Following Patton's classification (Patton, 2002), we carried out a triangulation of data obtained from different sources: the worksheets, the students' logs and the results of the structured interviews that took place at the end of the learning cycles.

The description of the attempts to do the tasks was made from the analysis of the electric circuits drawn by the students in the software, the students' explanations of the functioning of the circuits and the students' conceptions inferred by WLABEL, saved in the students' logs, as well as the number of attempts to accomplish the task. For instance, from the attempts done by the students a5 and a7 to do task five (figure 2), we can infer they assembled the two bulbs both in series and in parallel.

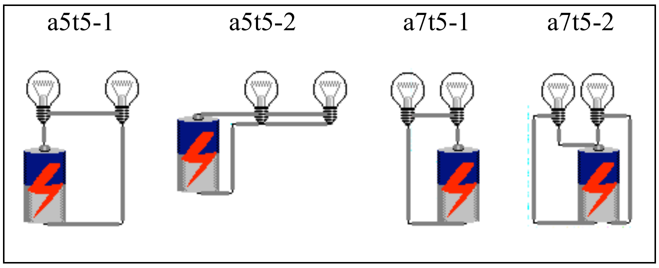


Figure 2. Students (a5 and a7) attempts to do task five

The explanations written by the students in the worksheet of the learning cycle three (table 2), helped us to conclude that, except one student, the boys enrolled in the experience could establish a relation between energy transfer and the potential difference applied to the circuit, the circuit type (series or parallel) and the bulbs characteristics (electric resistance), exploring both operational reasoning (using arguments such as how the bulbs are connected) and reasoning using the voltage concept.

Table 3. Explanations of the attempts to do task five, written by the students a5 and a7 in the worksheet of the learning cycle three.

Elève	Explication
a5	"I have assembled the bulbs in series (a5t5-1). The brightness of the bulbs is identical because the voltage applied is the same." "I have assembled the bulbs in parallel (a5t5-2). The bulbs are similar and have the same voltage applied to them. That is why they have the same brightness. The bulbs in parallel have a higher brightness than those in series because in that circuit the voltage is equal to that of the battery and in the series circuit the voltage is divided."
a7	"The bulbs are connected in series (a7t5-1). The bulbs have the same brightness because they have the same characteristics." "(the brightness) is different because instead of connecting the bulbs in series, I have assembled the circuit in parallel (a7t5-2), this means that in a series circuit the voltage is divided and in a parallel one it does not change."

The description of the attempts to do the tasks was also made from the students' logs. Those logs permit to infer the conceptions changed in the process. Table 3 presents examples of the conceptions changed during the learning cycle three, when the students where doing task five. In this table, "entity" is a variable and represents the concepts energy, electric current or electricity, depending on the most familiar term to the students. At the beginning of the work with WLABEL, the software asks the student – What does a battery supplies? The user has to select an answer – energy, electric current or electricity. During the work with the environment, from the menu « Option », the student can always change the answer.

In table 3, a grey square indicates a conceptual change. The numbers 1, 3 and 5 represent the electric circuit model attributed to the student by the software. "X" signifies that during a giving attempt the student decided to delete a conception previously selected. The electric model number five is the more similar to the scientific one. Taking that into account, from table 3 we can say that, for example, student a1 changed several conceptions to the model 5. Table 3 also shows that while some students made progressions toward conceptions closer to the scientific ones (a1, a6 and a7), one didn't progress at all (a4) and another one regressed (a2). In the course of the attempts to do task five, student a2 changed several conceptions from model 3 to model 1.

Table 4. Examples of the conceptions changed during the learning cycle three, task five. Entity can be either energy, electric current or electricity.

Contents of the conceptions	***a1***		**a2**			**a3**	***a4***		**a6**		***a7***
Conservation of the entity	*5*	*5*	3	X	*5*	3	*5*	*5*			*5*
Direction of the entity	*5*	*5*	3	X	*5*	3	*5*	*5*			*5*
Displacement of the entity	*5*	*5*	3	X	*5*	3	*5*	*5*		*5*	*5*
Value of entity in the source	X	*5*	*5*	*5*	*5*	3			X		*5*
Value of the entity in the receptor	1	*5*			3	3					*5*
Relation between voltage vs. entity	1	*5*	3	X	1	3	1	1		1	*5*
Definition of voltage/d.d.p.	1	*5*	3	1	1	3			X		*5*
Value of the voltage in the source	1	*5*	3	1	*5*	3			X		*5*

As described above, at the end of each cycle students had to draw their conclusions in the worksheet (answering the questions proposed in the beginning of the worksheet) and were interviewed by the researcher during the application phase. Tables 4 and 5 show the data collected during the third cycle.

Table 5. Questions/answers written by the students a5 and a7 in the third worksheet

Questions	**Answers of the student a5**	**Answers of the student a7**
Q1: How can you modify the energy transfer in an electric circuit?	"We can modify the energy transfer in a circuit by changing the applied voltage (by changing the battery or using more than one battery in series), by changing the bulb characteristics or by changing the circuit (series/parallel)"	"Changing the battery, i.e., the applied voltage, connecting more than one bulb in series or in parallel."
Q2: The energy transferred (transformed) in a receptor (a bulb) depends on what?	"The energy transformed in a receptor changes if the applied voltage higher or lower without changing the bulb or changing the connection of the bulbs."	"Changing the bulbs, changing the applied voltage or connecting more than one receptor in series or in parallel."

The objectives of the questions used in the application phase were: to make the prevision of the energy transfer in a house when a new appliance is connected (Q.1.1); to explain why does the fuse cut off the energy when another appliance is also connected (Q.1.2); to make previsions about the energy transfer in a series circuits (a Christmas Tree) without one of the bulbs; and, using the same context (two different Christmas Trees with different number of bulbs assembled in series), to test the acquisition of a correct relationship between the voltage applied to a receptor (a bulb) and the energy transfer (the brightness of the bulb). Table 5 synthesises the students' answers. The audio registration of the answers of one of the students, a2, was inaudible.

The triangulation of the data obtained described above was carried out to infer the reasoning made by the students. For instance, from explanations of the attempts to do task five and the conclusions, written by the student a7 in the worksheet, and from the results of the application phase for the same student, presented above (table 5), it can be observed that student a7, among others, reasons in terms of the potential difference during task 5, both for the explanation of the tasks and for the conclusions of the activities. However, the student experiences some difficulties on using this type of reasoning during the application phase.

Table 6. Students' answers given to the questions of the application phase of the third learning cycle. "✓" indicates a correct answer. The justifications signalled with a "•" are operational – students explained the phenomena referring only how the circuits were assembled.

Questions – Students' answers / Students	a1	a3	a4	a5	a6	a7
Q.1.1– The energy supplied to the circuit of the house increased when the computer was connected.	✓	✓		✓	✓	✓
Correct explanation	✓	✓•		✓•	✓•	✓•
Q.1.2– The fuse cut off the energy when a new appliance was connected because, given that the appliances are connected in parallel, the energy needed is greater than the maximum energy that could be supplied.		✓	✓	✓		✓
Q.2.1– The Christmas Tree stopped functioning because one of the bulbs was not connected and since the circuit is assembled in series, it is opened, which means that it hasn't any voltage applied.	✓	✓	✓•	✓	✓•	✓•
Q.2.2– The Christmas Tree that needs less energy is the A, because it has a greater number of bulbs.				✓	✓	✓
Correct explanation				✓	✓•	✓

4.2. Results of the triangulation of the data

The triangulation of the data obtained from the students' logs, the worksheets and the application phases allowed the identification of the students' conceptual evolution in each working cycle. In the following paragraphs we synthesise those results.

First working cycle: During this cycle the students had difficulties in assembling the circuits because they didn't know where the terminals of the circuit elements were, how to draw the wires to assemble them and how to connect the switches. The written descriptions of the circuits functioning in the work sheets was incomplete, not always clear, with spelling and syntax errors and focused in different aspects: circuit connection or/and how it functions, in energetic terms. For example, student a6 stated that to light a bulb he needs "two wires to connect the bulb and the battery to allow the electricity/energy to go to the bulb". Students felt very displeased to write these explanations. As mentioned by the students a7 and a3, "it is easier to explain things orally then by writing" and "writing is very boring". The majority of the students easily changed their conceptions about the number of terminals of the circuit elements and about the function of these elements. From the work sheets and from the results of the application phase we concluded that students acquired the notion that all the circuit elements have two terminals. They also developed operational rules for circuit connections and properly identified the conditions to have an energy transfer in a circuit and if there is, or not, energy and potential difference in a circuit. However, they had problems in relating those concepts.

Second working cycle: Tasks 3 and 4 were those with a larger number of tries to be completed. Moreover, students simulated the majority of the circuits general comments. To solve task 3, students drew circuits changing the battery or putting batteries connected in series and in parallel. The circuits drawn for task 4 had different bulbs and bulbs assembled in series and in parallel. Some students still showed problems with the number of terminals of the circuit elements and made regressions concerning this notion. Students' logs also showed conceptual regressions concerning other conceptions at this stage, because students changed or deleted some of the sentences chosen previously in the tables presented by WLABEL. But for students a2 and a7, all the others seemed to be more interested in assembling the circuits then in changing their conceptions. Some students did not explain the functioning of all their attempts to accomplish the tasks (once again showing a low motivation for this type of activities and poor literacy competences). Students a3 and a6 used common sense in their explanations: in task 3, the bulb brightness changed because they assembled a "stronger battery". The explanations written by the other students for the circuits drawn to acomplish task 3 reported how they assembled the circuit and the subsequent changes in the voltage across the circuit. They are expressed in operational or phenomenological (Tiberghien et al., 1995) and conceptual terms. Students' explanations for the circuits of task 4 are more operational: for one student, the brightness of the bulb changed because he "changed the bulb, put two bulbs in series or in parallel". However, these explanations also show that some students were able to relate changes in energy transfer with changes in the voltage applied to the circuit. In the conclusions of the work sheet, students also used the same reasoning and the variable time to explain changes in the energy transfer, but in the application activities they had problems in exploiting it.

Third working cycle: Students had fewer difficulties in assembling the circuits of tasks 5 and 6. The circuits drawn by the students to do these tasks have two bulbs connected in series or in parallel. The explanations of the circuits and the conclusions of the work sheet are more complete than those of the two first working cycles. They permit the conclusion that almost all the students (except a3) were able to relate changes in energy transfer with the potential difference applied, the type of circuit and the characteristics of the bulbs. One student (a2) used also the concept of electric current: the energy transformed in the bulb "depends on the source – the voltage applied, and the current, which depends on the bulbs characteristics and on the way the circuit is assembled". Like in the previous cycle, in the application activities, students' reasons are more operational. Some students regressed about the current conservation concept, since the conception "electric appliances use something (energy/electricity/current)" can be inferred from their answers.

Fourth working cycle: To do the tasks foreseen in this cycle, some students had problems in connecting the circuit elements. To accomplish task 7, they assembled the bulbs in parallel instead of drawing the circuit with the bulbs in series. The explanations were written in operational terms, identifying the ways the circuit elements are connected. In the conclusions of the work sheet, almost all the students explained correctly, but not always in a complete way, how they could change the energy transfer in a circuit and the differences between a series and a parallel circuit. For instance, student a5 stated that "the differences between series and parallel circuits are associated with the time duration of the battery, what happens when one of the bulbs blows up and the bulbs' brightness", relating them to the voltage applied. In the application activities the majority of the students could predict the brightness of different bulbs connected in series, parallel and mixed circuits and justify their answers taking into account the type of circuits and the potential difference applied to the bulbs.

5. Conclusions and final comments

From the students' conceptual evolution and taking into account the research questions mentioned in the section 3, we can conclude that:

- As Tao & Gunstone (1999) remarked students' conceptual evolution is a very unstable process and presents conceptual regressions. These authors reported conceptual regressions when students had to use the new conceptions in different contexts and used the notion of "status of conception" (Hewson & Hewson, 1992) to explain them. Our findings reinforce their conclusions and indicate that those regressions can also occur in the same context and that the intelligibility and plausibility of the scientific conceptions is inconstant.
- Experts adapt their reasoning to the context of the problem to be solved (Chi *et al.*, 1994). They explain why a bulb lights up in terms of processes. However, to explain the difference in brightness among bulbs they use the material attributes of the circuits, like the number of bulbs, how they are assembled, etc. The apparent regressions, especially in the application phases and in the last working cycles, may have the same kind of explanation.
- Students easily changed the conceptions about the conditions to have energy transfer in the circuit and the functions of electric elements (conceptions changed in the first working cycle). Conceptions related to different ontological categories (Chi *et al.*, 1994), like the potential difference and its relation with the energy transfer, took more time to be acquired.
- As Lee & Law (2001) reported, focusing student's attention on voltage changes encourages them to develop systemic reasoning, to explain changes in energy transfer using that concept, i.e., using a reasoning closer to the one used by experts (Stocklmayer & Treagust, 1996). The differentiation between energy and current involves the acquisition of Ohm's law and of the electrical resistance concept. Our strategies must be reformulated to permit this kind of learning.
- The activities avoided the development of alternative conceptions about the relation between current and potential difference and about the source function, which are two of the most resistant alternative conceptions about electricity concepts.

As a final remark, we would like to emphasize that, according to the teachers involved in the evaluation of the software, WLABEL has a high didactic quality, but its use in schools actually depends on both the material conditions of the schools and on the teacher's training to use this type of resources. The software is easily manipulated by the students and promotes conceptual change, although the conceptual evolution is different from student to student (as reported in other studies, for instance, Psillos, 1998, Tao & Gunstone, 1999, Lee & Law, 2001, or Missonnier, 2002) and depends on cognitive and personal and psychological factors (Loureiro & Depover, 2005).

Bibliography

Appleton, K. (1997), Analysis and description of students' learning during science classes using a constructivist-based model, *Journal of Research in Science Teaching*., *34*(3), 303-318

Boohan, R. (1992), DIAG: a Program to Diagnose Students' Models in Science, *Journal of Computer Assisted Learning*, 8, 206-220

Boohan, R. (1993), Using Computer-Based Questionnaires to Diagnose Students' Models of Electricity, In M. Caillot (Ed.), *Learning Electricity or Electronics with Advanced Educational Technology*, N.Y.: Springer-Verlag, 173-196

Brna, P. (1988), Confronting Misconceptions in the Domain of Simple Electrical Circuits, *Instructional Science*, 17, 29-55

Closset, J.-L. (1983), D'où proviennent certaines "erreurs" rencontrés chez les élèves et les étudiants en électrocinétique? Peut-on y remédier? *Bulletin de l'Union des Physiciens, 657*, 81-102

Chang, K-E., Liu, S-H. & Chen, S-W. (1998), A testing system for diagnosing misconceptions in DC electric circuits, *Computer & Education*, 31, 195-210

Chi, M. T. H., Slotta, J. D. , & de Leeuw, N. (1994), From things to processes: A theory of conceptual change for learning science concepts, *Learning and Instruction, 4*, 27-43

Finley, F., Lawrenz, F. & Heller, P. (1992), *A summary of research in Science Education 1990*, Columbus: ERIC/CSMEE Publications

Grob, K., Pollak, V.L. & Rhöneck, C. von (1993), Computerized Analysis of Students' Ability to Process Information in the Area of Basic Electricity, In M. Caillot (Ed.), *Learning Electricity or Electronics with Advanced Educational Technology*, N.Y.: Springer-Verlag, 197-210

Harvey, I. (1999), *LTDI Evaluation Cookbook*, Edinburgh: Learning Technology Dissemination Initiative

Härtel, H. (1982), The electric circuit as a system: A new approach, *European Journal of Science Education*, 4(1), 45-55

Harvey, I. (1999) *LTDI Evaluation Cookbook*, LTDI, Edinburg, 1999, [Online]. Access: http://www.icbl.hw.ac.uk/ltdi/cookbook/ (last viewed in 5/1/2005)

Hewson, P. W. & Hewson, M. G. (1992), The status of students' conceptions, In R. Duit, F. Goldberg, H. Niedderer (Eds.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 59-73), Kiel, IPN

Jaakkola, T. & Nurmi, S. (2004). *Academic Impact of Learning Objetcs: The Case of Electric Circuits*. Paper presented in BERA (British Educational Research Association) 2004 Conference, Manchester, UK, 16-18.9.2004 [Online]. Access: http://users.utu.fi/samnurm/Final_report_on_celebrate_experimental_studies.pdf (last visited in 6/4/2005)

Jaakkola, T., Nurmi, S. & Lehtinen, E. (2005). *In quest of understanding electricity – Binding simulation and laboratory work together.* Paper presented in AERA 2005 Conference, Montréal, Canada, 11-15.4.2005 [Online]. Access: http://users.utu.fi/samnurm/Understanding_electricity.pdf (last visited in 6/4/2005)

Jenkins, E.W. (2001), Research in Science Education in Europe: Retrospect and prospect, In H. Behrendt, H. Dahncke, R. Duit, W. Graeber, M. Komorek, A. Kross (Eds.), *Research in Science Education - Past, Present, and Future* (pp. 17-26), Dordrecht, The Netherlands: Kluwer Academic Publishers

Kearney, M & Treagust, D.F. (2001), Constructivism as a referent in the design and development of a computer program using interactive digital video to enhance learning in physics, *Australian Journal of educational Technology, 17*, 64-79

Lee, Y. & Law, N. (2001), Explorations in promoting conceptual change in electrical concepts via ontological category shift, *International Journal of Science Education, 23*, 111-149

Loureiro, M. João. (1993), LABEL: An intelligent Learning Environment (ILE) for Electric Circuits, In M. Caillot (Ed.), *Learning Electricity and Electronics with Advanced Educational Technology*, N.Y.: Springer-Verlag, 259-274

Loureiro, Mª João (2002), Un environnement d'apprentissage basé sur les conceptions alternatives des élèves – une application à l'enseignement de l'électricité, unpublished PhD thesis, Université de Mons-Hainaut, 349 p.

Loureiro, Mª João & Depover, C. (1999), WLABEL: un environnement d'apprentissage permettant le diagnostique des conceptions alternatives et la promotion du changement conceptuel, In C. Depover, B. Noël (Eds.), *L'évaluation des compétences et des processus cognitifs – Modèles, pratiques et contextes*, Bruxelles: De Boeck Université, 267-281

Loureiro, Mª João & Depover, C. (2005), Using ICT to promote learning in electricity: na evaluation study. In D. Koliopoulos, A. Vavouraki (Eds.), Science Education at the Cross Roads: Meeting the Challenges of the 21Th Century. Athens: Association for Science Education (EDIFE), 157-171

Missonnier, M-F. (2002), *Mise en évidence de chemins d'apprentissage des élèves lors d'une ingénierie didactique d'électrocinétique,* unpublished PhD thesis, Université de Paris 7

Moreira, A. P., Loureiro, Mª João, Marques, L.,(2004), Obstáculos à Integração das TIC no Ensino das Ciências: Percepções de Professores Orientadores de Estágio e Responsáveis pela Gestão das Escolas. In J.M. Pérez, J.A. Pulido, M. Rodriguez, B. Manjón, J. Rodríguez (Eds), *Informática Educativa – artículos seleccionados del VI Simpósio Internacional de Informática Educativa* [CD-ROM], Cáceres: Universidade de Extremadura

Paiva, J. (2002) *As Tecnologias de Informação e Comunicação: utilização pelos professores* (Dados relativos a 2001/2002). Lisboa: Ministério da Educação – DAPP

Patton, M. Q. (2002) *Qualitative evaluation and research methods* (3rd ed.), Thousand Oaks, CA: Sage Publications, Inc.

Pfundt, H. & Duit, R. (2002), *Bibliography - Students' Alternative Frameworks and Science Education* (4th Edition) [Electronically distributed], Kiel: Institute for Science Education

Psillos, D. (1998), Teaching introductory electricity, In A. Tiberghien, E. Jossem, J. Barojas (Eds.), *Connecting research in Physics education with teacher training* [Online]. Access: http://www.physics.ohio-state.edu/~jossem/ICPE/E4.html (last visited in 6/4/05), Ohio: I.C.P.E. Book © International Commission on Physics Education

Rhöneck, C. von, Grob, K. & Völker, B. (1998), Learning in basic electricity: how do motivation, cognitive and classroom climate factors influence achievement in physics? *International Journal of Science Education, 20*, 551-565

Stocklmayer, S. et Treagust, D (1996), Images of electricity: how do novices and experts model electric current? *International Journal of Science Education, 18*, 163-178

Tao, P-K. & Gunstone, R.F. (1999), The process of conceptual change in force and motion during computer-supported physics instruction, *Journal of Research in Science Teaching*, *36*, 859-882

Tiberghien, A., Psillos, D. & Koumaras, P. (1995), Physics instruction from epistemological and didactical basis, *Instructional Science, 22*, 423-444