Conceptual and exploratory labs for secondary teacher education in two different countries. The case of dc circuits

View the article online for updates and enhancements.

IOP **ebooks**™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Conceptual and exploratory labs for secondary teacher education in two different countries. The case of dc circuits

Jenaro Guisasola[1], Marisa Michelini[2], Alberto Stefanel[2], Kristina Zuza[1]

[1]Applied Physics Department, University of the Basque Country (UPV/EHU), Spain
[2]URDF University of Udine, Italy

Abstract. We analyse the effectiveness of our Formative Intervention Module (FIM), where our was to support a groups of 46 pre-service technology secondary teachers at the University in Udine and a group of 32 pre-service technology teachers at the University of the Basque Country. The topic of the formative intervention was DC circuits because it is a topic that is mentioned in the technology curriculum of any country. The research problem considers how we succeeded in promoting formative modules by promoting new learning materials and by organizing pre-service training. In particular we evaluate the pre-service teachers achievement both in understanding the concepts and in the acquisition of pedagogical content knowledge. A qualitative pre/post-test was designed to get data and analyse the impact of the formative intervention module. We find a generalized improvement in the macro-physical description of a simple DC (Direct Current) circuits. In addition, around two third of future teachers recognized learning difficulties for understanding concepts and the alternative conceptions of students.

1. Introduction

There is a big amount of research on students' difficulties and alternative conceptions in learning DC circuits in Secondary and University levels. Physics Education research has established well Secondary students difficulties regarding the learning of a macroscopic model of how dc circuit works. The literature has showed that a significant portion of Secondary teachers has also problems with a global scientific understanding of the DC circuits. Sometimes the teachers confuse the concepts of current and potential difference (cita), the influence of the topology of the system or, they have difficulties in applying the energy conservation. However, there are few studies that propose and evaluate formative courses for teachers for overcoming the mentioned problems. Moreover, we notice that the teaching and learning problems on DC circuit are concerned not only to the science curriculum but also to the technology curriculum, because the topic is in both. Often, technology is taught using the "black box principle": the students first finish the technological project and after, they learn the concepts and laws related to the project. In technology, practical applications may overcloud the physical concepts and laws that are behind the technological project or machine (Yager 1996).

A Formative Intervention Module (FIM) was designed taking in mind the demands of new standards in Science and Technology and, previous results of the educational research in DC circuits (Cohen *et al.* 1983, McDermott 1991, McDermott & Shaffer 1992, Hart 2008, Glauert 2009, Gunstone *et al.* 2009). The first main goal is related with conceptual expertise of the future teachers on conceptual knowledge on simple DC circuits highlighting the importance of the interpretative model. The second goal is related with the didactic perspective and the acquisition of pedagogical content knowledge. The FIM was implemented in two countries in the University of Udine (46 pre-service low

secondary teachers) and in the University of the Basque Country (25 pre-service low secondary teachers). One of the tools for research our goals were to create teaching materials that would allow to study the basics of DC circuits, following the educational path proposed by us in previous studies (Testa & Michelini 2007, 2008; Guisasola *et al.* 2008). We included in the teaching materials conceptual and explorative labs activities. Through labs activities pre-service teachers, have the opportunity to understand what happens in an electrical DC (Direct Current) circuit and build the model of a circuit and, at the same time, acquiring scientific skill (Testa & Michelini 2008). It is underlined the importance of the educational labs where future teachers can directly be involved and immersed in an educational path to experience the phenomenological exploration of the phenomena (Michelini 2004, McDermott *et al.* 2000, Sokoloff *et al.* 2004, Eylon & Bagno 2006). It is essential the transition between the experiment results and the modeling of the phenomena (Hart 2008, Gilbert & Justi 2016, Windschitl *et al.* 2008). We feel that technological curriculums should include the knowledge in science and technology, linking the learning of knowledge to the acquisitions of skills (Koballa *et al.* 1997). Working with an electric circuit project, for example, may improve general understanding of model of current and working skills that allow bringing the experimental data and explicative models.

The FIM was planned keeping in mind the results from studies made by Shulman (1986) and Roth (2007), between others that contributed to define the Pedagogical Content Knowledge (PCK) as the knowledge that teachers develop to help others to learn and that they build according to the specific topics of their area of knowledge. This knowledge includes not only the knowledge of the discipline, but the analysis and reflection about learning objectives and active experiences of educational paths (Gess-Newsome 1999, Magnusson *et al.* 1999, Etkina 2010, Guisasola *et al.* 2013, Michelini *et al.* 2013). One of the tools for working pre-service teachers PCK was to create a package of task that would allow reasoning ways of learning the foundations of the DC circuits according with the curriculum teaching objectives and their and/or students' learning difficulties.

The FIM was designed looking to the competencies that future teachers have to develop during their formation and other aspects as attitudes or STSE aspects were included in the design. The proposed activities are grounded on active learning strategies giving to the Pre-Service Teachers (PT) opportunities for building and discussing of DC circuit models to work in the objectives presented in the table 1.

Table 1. Relation of the content related objectives of the FIM

Objective	
1	Explicative model of simple resistive DC circuit
2	Distinguishing series and parallel conditions with simple DC circuits and functioning according different perspectives (e.g. topological perspective, Current-resistance-Tension one)
3	Overcome the main conceptual knots as those on the functioning of the circuit and topological one (e.g. equivalent circuits)
4	Deeper explicative model: attribute role the battery; meaning of battery as a tension generator

In addition to developing the study materials, the pre-service teachers (PT) were given training in the teaching of the DC circuits. This training was organized during a one course for science and engineers who wanted to become Secondary science and technology teachers. The characteristics of the course are described in the next section.

The research problems of the presents study are linked to the principal goals of the FIM. There are two main research questions:
- − To what extent have we succeeded in the production of new materials and the organization of training in relation to the pre-service teachers' understanding of the scientific model of electrical circuits?
- − To what extent have teachers acquired the PCK through the use of course materials?

2. The study

To answer the proposed research questions we implemented the FIM in two universities (University of Udine, UD) and (University of the Basque Country in Donostia, UPV/EHU-DO) in two different European countries (Italy and Spain). Although the two courses are not exactly the same there were many similarities concerning, for instance, educational approach, based on problem-solving and the experiments, reflections on conceptual knots and, development of conceptual model. The most important is that the learning goals concerning conceptual knowledge and PCK of both courses are very similar and that implies that both PT courses are comparable. The course done following the FIM in the University of Udine (4 ECTS) was implemented twice; at all 46 PT were enrolled aged between 30 and 60. In the University of the Basque Country the course (3 ECTS) was implemented once and there were enrolled 32 PT aged between 23 and 50. Table 2 resumes the degrees of the PTs in the two contexts.

Table 2. Degrees of the PTs involved in the two courses in Udine and Donostia

Degree	UD1 (N1 = 27)	UD2 (N2 = 19)	DO = UPV/EHU (N3 = 32)
Engineering	3	1	20
Architecture	21	17	6
Computer Science	1	1	6
Agronomy	1		
Chemistry	1		

The approach was the same in both courses adopting similar teaching. The course in Udine was organized as an educational lab including tutorials, experiments, interactive lectures demonstrations, design activities, questionnaires (Testa & Michelini 2007). The course in the UPV/EHU adopted an Interactive Teaching methodology through Project/Problem based learning, without "lecture", with lab experiments imbibed into the classroom activities. In appendix I some examples of analogous task that were implemented and adapted in the two context are given. Table 3 summarizes both teaching approaches.

Table 3. Schema of the Teaching Educational Approach, indicating, per each experiment, subject and typology of activity carried out (PS-Q: problem solving based on qualitative analysis; SQ: Semi-quantitative experiment; Exp: quantitative measurement-experiment; Exe: exercise). "U" means University of Udine and "D" means University of the Basque Country

Experiment	Subject	PS-Q	SQ	Exp	Exe
Circuit with bulb, battery, wire	Closed circuit → e. Current	U; D			
Circuit with bulb, battery, wire, different objects	Insulator; conductors, semiconductors	U	U		
Circuit with battery, wire and bulb in different positions → Ammeter, Voltmeter	The current is the same in all the section of a series circuit powered in continuous Tension is distributed	U; D	U; D	U; D	
Circuits and a series of batteries	The tension is an additive quantity	U	U		
Circuit with Parallel/series bulbs	The brightness → the current → Tension distribution, nodes law	U; D	U; D	U; D	U; D

	Systemic nature of circuits Equivalent load	U; D	D	U; D
Circuit with Parallel/series LED-		D	D	D
Logic Circuit	Equivalent functioning and topological differences	U; D		
Characteristic current-tension for a metallic wire	Ohm (DV = RI), (R = ρL/S) laws		U; D	

To analyze the effectiveness of the materials of the FIM and answer the research questions, a questionnaire composed by 4 questions was designed to administrate as pre-test and post-test instrument in both universities. In table 4, the relation between the objectives of the FIM and the research questions and the questions is shown.

Table 4. Objectives involved in each questions of the test and RQ focussed

Objective Research Question	QuestionQ1	Question Q2	Question Q3	Question Q4
Objective O.1.	x			
Objective O.2.		x		
Objective O.3.		x		x
Objectiv O.4.			x	
Research Question1.		x	x	x
Research Question2.	x			

The questionnaire is physics education research informed and is based on the learning difficulties and reasoning detected in previous research works (Cohen *et al*. 1983, McDermott 1991, McDermott & Shaffer 1992, Hart 2008, Glauert 2009, Gunstone *et al.* 2009). In appendix II there are the four questions. For the internal validity of the questionnaire three independent teacher who were experts in the teaching the topic, were asked to respond the questions and to analyze the objectives of the questions. They made suggestions that were taken into account when writing its final version. All faculty members confirmed that the contents of the questionnaire and the objectives were appropriate. Additionally, a pilot study was conducted with small samples of students. This confirmed that students generally had no problem understanding the meaning of questions.

3. Data analysis and results

The analysis of each question was made twice from two different points of view. The first analysis was done regarding to the final answer and they were classified taking into account the correctness of the answer. In the second analysis the interpretative approach was studied. PT' answers were analyzed independently by two researchers; Cohen's kappa reliability coefficient averaged 0.86 for the questions, indicating very good concordance in the judges' criteria for setting the categories described. The intra-rater reliability kappa coefficient was also calculated for the main researcher three weeks later, obtaining a value of 0.87, on average, for all the questions, which is satisfactory for a level of confidence of 95%. The results of these semi-quantitative analysis are shown in frequencies comparing pre-test and post-test situations and different cohorts for Udine and The Basque Country.

We will present some results from three questions. In the first question Q1 of the questionnaire a simple situation is proposed (See Appendix II: Q1). A circuit is formed by a 4.5 V battery, connection wires, a bulb, a switch. When you close the circuit, the light bulb turns on. The PTs were request-

ed to discuss the model that can explain this fact. In the second part of the question Q1, they have to discuss some typical student responses and illustrating the reasoning that underlies each model. PTs answers were classified according to the qualitatively different criteria to analyze the students reasoning (see table 5). We defined four categories of explanation for the Q1.2:

- A. *Scientific:* The PT explains the scientific concept involved, don't considering the sentences of students
- B. *Correction:* The PT corrects the students answer, evidencing often what is wrong
- C. *Correct/incorrect:* The PT indicates when the answer is correct or incorrect (without explain why)
- D. *Student reasoning:* The PT indicates the students reasoning (in his opinion)

The results of question Q1.2 obtained in pre-test and post-test in both samples are shown in table 6. In this case the explanation given by students for each model proposed were analyzed and categorized in one of the explanation described before. We found that in both universities have grown two categories (correction on the answer and student reasoning) and "correct/incorrect" and "No answer/no explanation" (NA/NE) categories have decreased.

Table 5. Percentage concerning PTs analysis of students responses proposed in Q1

Q1.2	A. Scientific explanation		B. Correction		C. Incorrect		D. Student reasoning		E. NA/NE	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
UPV/EHU	7.0	3.0	40.0	77.0	35.0	0.0	15.0	20.0	3.0	0.0
U. Udine	0.0	6.5	28.0	32.5	15.5	3.0	11.0	41.0	45.5	15.5

In table 5, the percentages of pre-test students' responses showed problems in learning knots concepts for the UD cohort (45.5% of the total), due probably to the poor scientific baggage of the PT's. The answering PT's usually addressed in terms of accuracy / inaccuracy of the responses of the students (15,5-35% in category C) or indicating in what respects the response was scientifically wrong (28-40% in category B).

In the post-test, 41% of UD cohorts indicate the reasoning underlying the responses of the students and 20% of UPV/EHU cohort (see category D). However, in University of Udine there is a higher percentage of NA/NE than in UPV/EHU, after teaching the FIM. These different percentages in the groups of UD and UPV/EHU reflects, firstly, the different backgrounds of PTs (basically architecture for UD cohorts; engineering for UPV/EHU cohort), and, secondly, the more number of tasks devoted in UD to the analysis of the conceptual problem of pupils. 77% of UPV/EHU cohort and 32.5% of UD cohorts explain in what sense the students' response was not correct scientifically (see category B). 7.5% provides an analysis on the scientific level of the situation and 3.5% simply indicate whether the students' answers are correct or incorrect (see category C), which is an explanation more superficial of the explanations from category B.

In the two contexts, significant changes are evident comparing pre/post results. In addition to the change in the percentages, there are changes in relation to the quality of the explanations. The vast majority of the post-test answers are in the categories A, B and C. On the one hand, the categories A and C (18.0% UPV/EHU and 17.5% UD) are principally related to the scientific understanding of the DC circuits and the PTs' explanations critics the different options of the question Q1.2 from this point of view. On the other hand, a significant percentage of answers analyze each sentence of the question Q1.2 from the point of view of PCK taking in mind students alternative models (77% UPV/EHU and 32.5% UD). In total, the vast majority of the answers in the post-test show PTs' progression in learning DC circuits explicative model. Some standard examples of the progression in both understanding and acquisition of PCK are showed following:

There is current flow only from the positive pole to the bulb. There is no current flow that comes out from the base of the bulb since the current is used to turn on the bulb. For circulating current is necessary to have a closed circuit (understanding of the model of the circuits, Q1.1)

The same student explaining the options of Q1.2 writes:

Model A and B suppose no circulation of the current for all circuit. According to these interpretations is implicit that the bulb uses all the current or that the bulb sucks current from each pole. Model C supposes that the electric current go form positive pole to negative but is not correct that the current decrease after pass through the bulb. Although the bulb consumes energy, but the current is the same in all circuit. Model D is the correct answer because users do not consume current

In question Q2, three bulbs connected in parallel in an unusual way are presented (see Appendix II). In the first part of this question, PTs are request to compare the brightness/current of each bulb. In the third part, the bulb 3 is short cut and PTs have to answer if something changes due to that short cut.

Table 6. PTs percentage of answers on the question posed in Q2.1. The expected answer was $i1 = i2 = i3$

Q2.1	L1 > L2 > L3		L3 > L2 > L1		L3 ≠ L2 = L1		L1 = L2 = L3 ($i1 = i2 = i3$)		NA/NE	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
UPV/EHU	0.0	0.0	0.0	0.0	81.0	51.5	15.0	48.5	4.0	0.0
U. Udine	4.5	0.0	6.5	0.0	26.0	41.0	19.5	56.5	43.5	2.5

Table 6 reports the percentage of PTs answers to the question Q2.1. In the pre-test the answering prevalently do not recognize the equality of brightness/current. Moreover, in Udine almost an a half do not answer. In the post about a half of the answers in both UPV/EHU and UD, gave the expected answer (48.5% UPV/EHU and 56.5% UD). However, a significant part of PT evidences difficulties in recognizing the topology of the circuit and in particular the equivalent role of L3, with respect to the role of L1 and L2 (51.5% UPV/EHU and 41.0% UD).

Standard examples of the answers in the pre-test for category L3 ≠ L2 = L1 is the following:

The bulbs I1, I2 are connected in parallel, the L3 bulbs with the L1 + L2 group also in parallel. The brightness will be different: L1 = L2 but less than L3.

L1 and L2 equal to each other. L3 different from L1 and L2 (+ light); The I is divided into 2 point A (and becomes i1 and i2); i1 is still divided into i3 and i4.

This type of reasoning remains the same for the answers in the post-test.
A standard example of the correct answer in the post-test is:

Equal brightness because they are in parallel. That is, we have the same voltage in L1, L2, L3. while the current is distributed.

The vast majority of the answers in the pre-test use typical local reasoning, based on incorrect assumptions, which led to wrong answers (as see in table 6). In contrast, in post-test there is a significant improvement in understanding the circuit as a system.

Question 4 is similar to the question Q2 but in an academic context familiar to PT. Regarding to the final answer and if we compare with question Q2.1, the success of the students is much better. Even in the pre-test the answer are quite good (52% in Udine and 88% in UPV/EHU). In the post-test almost

100% gave the correct answer. In table 7, the comparison of the answers of questions Q4 and Q2.1 is presented regarding to the line of reasoning used in the answers, that includes conceptual comprehension of the aspects listed before. Here we stress on the following points: the Explanation A is given in the Q2.1 post-test by 48-30.5% of PTs and only by 15.5% in the Q4 post-test; the equal tension for each bulbs (absent in the pre-test) was given by 52% in UD and 16% in UPV/EHU; other naïve answers pass from 41/51.5% to 10.5/22%. It is evident the different explanation perspectives used, according to the different context considered.

Table 7. Comparison of PTs percentage of answers to question Q2.1 and Q4

Q2.1 and Q4	Udine Q2.1		UPV/EHU Q2.1		Udine Q4		UPV/EHU Q4	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
A. Bulbs/resistance in parallel	9.0	48.0	11.0	30.5	19.5	15.5	18.0	15.5
B. Nodes law ($i_{in} = i_{Out}$)	6.5	9.0	41.0	18.0	6.5	20.0	4.0	19.0
C. Equal current	0.0	0.0	0.0	0.0	2.0	2.0	37.0	28.0
D. Different length of the arms	6.5	2.0	0.0	0.0	11.0	0.0	7.5	0.0
F. Equal ΔV	0.0	0.0	0.0	0.0	9.0	52.0	22.0	15.5
G. Others	78.0	41.0	48.0	51.5	52.0	10.5	11.5	22.0

4. Conclusion and implications

We have noted the demands of new standards in Science and Technology. We have considered a common topic (electric circuits) in both the curriculum in science and technology to develop a formative intervention module for Pre-service Teachers (PT) who will teach technology and/or science in secondary education (12-16 years old students). It came as a surprise that the knowledge of cohort of engineers and architects from both countries, reacting spontaneously to pre-test, gave very poor arguments and show poor understanding on DC circuits.

A FIM on DC circuits based on exploratory and conceptual activities was designed for the preparation of secondary pre-service teachers of technology. Furthermore, this module was implemented in two universities of Europe: University of Udine (Italy) and UPV/EHU (Basque Country, Spain). Two courses were implemented adopting a similar operative approach, adapted in two different national contexts. The aim of the FIM is to improve the competencies of the prospective teachers in the interpretation of the topology and functioning of DC circuits, using physics concepts to construct interpretive model, in a way that allow them to provide to pupils the understanding on the topic of DC circuits.

As instrument for data collection we used a pre/post-test concerning the learning conceptual and didactic objectives of the FIM and based on open questions. The analysis of the PTs responses, give us the opportunity to answer to the research questions.

Concerning how the organization of training with the new materials improve the understanding pre-service teachers the understanding of the main conceptual aspects of DC circuits (RQ1), we find a generalized enhancement in the macro-physical description of a simple DC circuit using basic concept as current, potential difference, resistance, the equivalence of the circuit and batteries. More precisely, from pre-test to post test the PTs have demonstrated a higher level of skill acquisition. One of the best examples of that is the evolution of the percentage of correct answer and PTs that do not answer the questions.

Concerning how the teaching educational approach contribute in gaining PCK competencies on DC electrical circuits (RQ2), prospective teachers changes the ways of analyzing the conceptual problems related to the conceptions at the base of students' reasoning (almost 2/3 in Q1). PTs overcome the initial tendency of teachers to evaluate the student answer only as correct/incorrect. It emerges the competence on critical analysis on the scientific point of view. The majority of PTs passed from the

manipulation of circuit to conceptual construction of concepts using an operative/experimental approach.

The outcome of the FIM is good when compared with the results of the traditional teaching in other studies. This study reveals information about the attainment of project goals, which are to help PT to acquire, on the one hand, the concepts and skills in the basis of explanatory model of DC circuits and, on the other hand, the necessary PCK for a good teaching of the topic. However, the study does not give information about the pre-service teachers teaching strategies when they teach the topic in Secondary school. Therefore, further research will be necessary aiming to determine the pre-service teachers educational practice when they teach the topic.

References

Cohen R., Eylon B. & Ganiel U. (1983) Potential difference and current in simple electric circuits: A study of students' concepts. *American Journal of Physics* **51**, 407-412.

Etkina E. (2010) Pedagogical content knowledge and preparation of high school physics teachers, *Physical Review Special Topics Physics Education Research* **6**, 020110.

Eylon B.-S., Bagno E. (2006) Research-design model for professional development of teachers. *Physical Review Special Topics Physics Education Research* **2**, 020106.

Gess-Newsome J. (1999) PCK: an introduction and orientation. In *Examining pedagogical content knowledge* (Gess-Newsome J. &. Lederman N.G, Hrsg.), Dordrecht: Kluwer, pp. 3-17.

Gilbert J.K. & Justi R. (2016) *Models and Modeling in Science Education* **9**, Dordrecht: Springer.

Glauert E.B. (2009) How young children understand electric circuits: Prediction, explanation and exploration. *International Journal of Science Education* **31**, 1025-1047.

Guisasola J., Barragués J.I. & Garmendia M. (2013) El Máster de Formación Inicial del Profesorado de Secundaria y el conocimiento práctico profesional del futuro profesorado de Ciencias Experimentales, *Matemáticas y Tecnología, Revista Eureka sobre Enseñanza y Divulgación de las Ciencias* **10**, 568-581.

Guisasola J., Michelini M., Mossenta A., Viola R (2008) Teaching electromagnetism: issues and changes. In *GIREP-EPEC Conference Frontiers of Physics Education 2007. Selected Contributions* (Jurdana-Šepić E. *et al.*, Eds.), Zlatni rez: Rijeka, pp. 58-76.

Gunstone R., Mulhall P. & McKittrick B. (2009) Physics teachers' perceptions of the difficulty of teaching electricity. *Research in Science Education* **39**, 515-538.

Hart C. (2008) Models in physics, models for physics learning, and why the distinction may matter in the case of electric circuits. *Research in Science Education* **38**, 529-544.

Koballa T., Kemp A. & Evans R. (1997) The spectrum of scientific literacy. *Science Teachers* **64**, 27-31.

Magnusson S., Krajcik J. & Borko H. (1999) Nature, Sources, and Development of PCK for Science teachers. In *Examining PCK* (Gess-Newsome J. & Lederman N.G., eds.), Dordrecht: Kluwer, 95-132.

McDermott L.C. (1991) What we teach and what is learned: Closing the gap [Millikan Lecture 1990]. *American Journal of Physics* **59**, 301-315.

McDermott L.C. & Shaffer P.S. (1992) Research as a guide for curriculum development: An example from introductory electricity. *American Journal of Physics* **60**, 994-1003.

McDermott L.C., Shaffer P.S., Constantinou C.P. (2000) Preparing teachers to teach physics and physical science by inquiry, *Physics Education* **35**(6), 411-416.

Michelini M. ed. (2004) *Quality Development in the Teacher Education and Training,* selected papers in Girep book, Udine: Forum.

Michelini M., Santi L. & Stefanel A. (2013) La formación docente: un reto para la investigación, *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias* **10**, 846-870.

Shulman L.S. (l986) Those who understand: knowledge growth in teaching. *Educational Researcher* **15**(Z), 4-14.

Roth K.J. (2007) *Science Teachers as Researchers*. In Handbook of Research on Science Education (Abell S.K. & Lederman N.G., eds.), N.Y.: Routledge, pp. 1205-1259.

Sokoloff D.R., Lawson P.W., Thornton R.K. (2004) *Real Time Physics*, New York: Wiley.

Testa I., Michelini M. (2008) Supporting global reasoning in electric circuits: a functional approach to address common misconceptions about electric circuits. In *GIREP-EPEC Conference Frontiers of Physics Education 2007. Selected Contributions*.(Jurdana-Šepić E. *et al.*, eds.), Zlatni rez: Rijeka, pp. 77-80.

Testa I., Michelini M. (2007) Prospective primary teachers 'functional models of electric and logic circuits. In *Modelling in Physics and Physics Education* (Van den Berg E., Ellermeijer T., Slooten O., eds.), Amsterdam: University of Amsterdam, 391-404.

Windschitl M., Thompson J. & Braaten M. (2008) Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations, *Science Education* **92**, 94.

Yager R.E. (1996) Science/Technology/Society as Reform in Science Education. Albany: State University of New York.

APPENDIX I

Examples of activities used in the FIM implemented the University of Udine and in the University of the Basque Country. A) Circuits with a battery and a bulb used in the Udine and Donostia courses. B) Circuits connecting a battery to parallel/series bulbs and C) examples of operative introduction of the role of battery in a circuit (tension generator), comparison of the bulbs brightness.
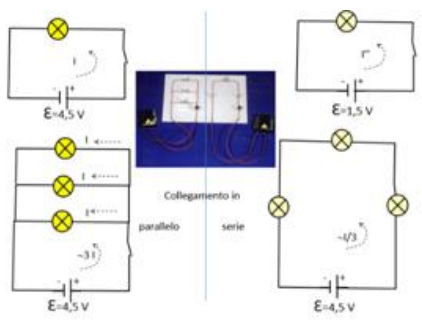
University of Udine   UPV/EHU

APPENDIX II

Q1. A circuit is formed by a 4.5 V battery, connection wires, a bulb, a switch. When you close the circuit, the light bulb turns on.
1.1 Which is the model that can explain that?
....
....
....

1.2 Please, discuss some typical student responses, illustrating in particular the reasoning that underlies each model:

Model A: There is current flow only from the positive pole to the bulb. Any current flows from the base of the bulb since the current is used to turn on the light bulb

Model B: The current flows from each of the two poles of the battery to the bulb (it lights up for the clash of the two currents in the opposite direction)

Model C: The current circulates always in the same direction around the circuit, but his intensity is lower after the bulb

Model D: the current circulates in the same direction and with the same current throughout the circuit.
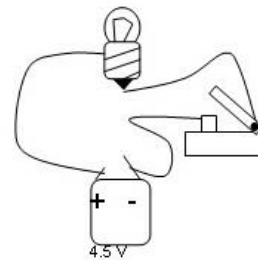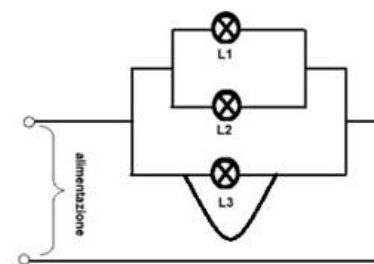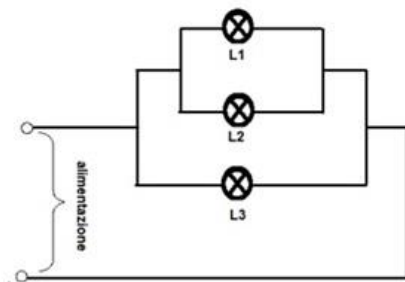
Q2.

Q2.1 What will be the brightness of each of the bulbs (I1, I2, I3, respectively)? Explain

Q2.2 Changes the brightness of the bulbs if unscrewing L3? Explain

Q2.3 Changes the brightness of the bulbs if you short L3? Explain

Q4. Consider the circuit formed by three identical bulbs connected in parallel, a switch and a battery.
When the circuit is closed, the brightness of each bulb will remain the same?
Explain your answer.