

DESIGNING AND EVALUATING A RESEARCH-BASED TEACHING SEQUENCE FOR ELECTRICAL CAPACITANCE

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ABSTRACT

This presentation examines the didactic suitability of introducing a teaching sequence when teaching the concept of electrical capacitance in the context of charging a body. This short sequence targets first year university students and was designed following students' common conceptions on this topic. The evaluation is made by comparing the results with a control group using written questionnaires. The results show that the elements within the sequence help students to establish a connection between the movement of charges (micro frame) and the energetic analysis of the system (macro frame).

KEYWORDS

Teaching electrical capacitance, university level, model of explanation of electrical charge of bodies

INTRODUCTION

The concept of charge and the properties of charged bodies are an important part of physics instruction at many different levels. Students learn the idea of charging in elementary school and gradually integrate more complex ideas to interpret electrical phenomena. Study of the models to interpret electromagnetic phenomena is a rich area, providing a solid basis for understanding everything from the electromagnetic nature of matter to the basis of contemporary technology. The structure of the electromagnetic nature of matter is both beautiful and useful. Furthermore, the electromagnetic theories provide a good context for teaching scientific reasoning skills such as model-building and making relations between macroscopic phenomena and microscopic theories.

In Physics and engineering graduate schools, students continue to learn more detailed theories for describing the electrical properties of charged bodies. Usually the electricity syllabus for introductory physics courses starts by studying point charges and charged bodies at rest (electrostatics) in order to be able to analyse the movement of charges in direct current electrical circuits later. However, it does not usually make provision for a teaching sequence which analyses the transition of specific charges to charged bodies, and constructs an explanatory model of the charging processes on a body. These processes are essential in the model which explains the fundamental electrical process, for two reasons. Firstly, the processes to charge a body cause an initial transition from electrostatics to electrokinetics, even though the context is not a conventional electrical circuit. In this case it is necessary to analyse how the charges move from a battery to the charged body. The explanatory model requires significant knowledge of the electrical nature of the materials and brings together the concepts of electrical charge and electrical potential. Secondly, most frequent technological applications for electrical processes require bodies which are capable of accumulating a lot of charge at a low cost. This was a tricky relevant historical problem which required a new concept to be introduced: electrical capacitance (Guisasola et al. 2002).

In this paper, we will focus on the model which explains the processes of charging bodies and the concept of electrical capacitance. Learning which includes understanding the concept of electrical

capacity implies not only knowing how to calculate size on the basis of the formula for it, but knowing that it is necessary to be aware of what goes on during the process of charging a body. In order to relate “operational” reasoning based on a rule or formula, for example $C=Q/V$, to “causal” reasoning based on what happens and changes during the process of charging a body, it is necessary to implement systemic reasoning. This reasoning is based on considering the interactions between the different parts (battery-environment-body to be charged) and the changes which take place (passage of current) which may explain the “mechanisms” which enable a new equilibrium to be established. It must also be made clear that the potential electrical energy acquired by a body on being charged is due to the work carried out by the environment during the process. Talking of the potential energy of a charged body and the environment enables us to establish a “mechanism” for explaining the new equilibrium achieved (Chabay & Sherwood 2002).

One controversial question in teaching the concept of electrical capacitance is whether and how to teach it at high school level. This is a topic of active debate among Spanish high school teachers. In the last Spanish curricular reform for science in high school standards state that students should be able to explain the movement of charges in conductors and the processes of charging bodies but do not state that it is though the concept of electrical capacitance. We therefore have to consider, at least within the framework of education in Spain, that students will study these subjects in physics courses for the first time in their first year at university. This implies that it may not be assumed that students are familiar with the processes for charging bodies or with apparatus such as condensers.

PREVIOUS RESEARCH AND STUDENTS’ DIFFICULTIES IN LEARNING ABOUT ELECTRICAL CAPACITANCE

Several studies point out that undergraduate students have difficulties when analyzing the behaviour of matter in the face of electrical interaction (Guruswamy et al., 1997; Furió & Guisasola, 1999; Park et al., 2001). The lack of knowledge of the electrical nature of objects has been mentioned as one of the reasons for the occurrence of these problems. Park et al. (2001) show that 50% of first-year university students believe that an electric charge cannot flow through insulators. As a result, electrical polarization phenomena are not properly interpreted (Viennot, 2001, Galili, 1995; Furió et al., 2004). Several investigations confirm that most students had a lack of knowledge regarding the meaning of terms such as potential and potential difference, which they frequently use as isolated and undefined concepts (Thacker et al. 1999, Psillos 1998). Students and some teachers (Mulhall et al., 2001) avoid the use of those terms, even if they are specifically required to do so (Stocklmayer & Treagust, 1996). Instead, they use terms like charge or electricity. Research shows that the concept of potential difference is masked by the concept of charge, hence losing its own meaning; as has also been mentioned by Benseghir & Closset (1996).

Regarding the processes of electrical charging of bodies and the concept of electrical capacitance, most undergraduate students explain these processes as the passing of charges which go from the generator to the body to be charged. They explain that the passage of these charges is due to the difference in the amount of charge between both. In these explanations it is not necessary to discuss the difference of potential between the bodies to explain the charge process. Likewise, the concept of electrical capacitance is understood as being the quantity of charge that can be stored in a body and, therefore, this concept has no significance for uncharged bodies (Guisasola et al 2007). Furthermore, a significant number of students unintentionally use the formula for electric potential and electrical capacitance. It seems that when failing to make any sense of concepts, students take refuge in operative definitions and reason on the basis of these (Viennot 2001).

Finally, research shows that avoiding the discussion of topics likely to lead to misconceptions does not work (Bransford J.D. et al., 1999). It is much more effective to explicitly address the problem students are likely to encounter. This approach is important when discussing the teaching of electrical capacitance and the model explaining the process of electrical charging of bodies at university level.

Students learn the properties of charged bodies in Secondary School and in popular culture, so they start university courses with preconceived ideas about electrical processes, whether we like it or not.

THE STUDY

Our basic research question is: How to design a teaching sequence of electrical capacitance and implement it effectively? In accordance with Meheut and Psillos (2004), we understand by ‘teaching-learning sequence’ a term widely used to denote the close linkage between the proposed teaching and the expected student learning outcomes of a research-based, topic-oriented sequence. The approach presented here falls within the line of research where teaching and learning are investigated at detailed level (involving a single topic sequence) rather than at a whole curriculum level, carried out over one or two years.

The context of the study is a transformed Introductory Physics Course for first-year Engineering degree students, taught by the authors over two years (2004-05, 2005-06), using the same material. The course format was interactive learning context (Guisasola et al 2008), with an enrolment of 42 (Group E1) and 45 (Group E2) in 04-05 and, 45 (Group E1) and 43 (Group E2) in 05-06. The content of the course emphasized connections with social scientific problems and everyday technological applications, scientific reasoning and qualitative approaches to concepts and theories. The teaching material of the transformed course is available on the web for the students at our university. We also chose also 65 students as control groups (Group C, two classes), who took the same syllabus but the course format was lectures. Both the experimental and the control groups followed the same syllabus. The syllabus for Electricity and Magnetism is similar to that used in many Introductory Physics Courses for Science and Engineering, such as Tipler & Mosca (2004). However, the control students do not normally have the opportunity to participate actively and they are limited to taking notes from the teacher’s explanations. On the other hand, All students had previously followed at least two physics courses involving topics on electromagnetism during 16-18 post-compulsory education, and they passed an exam to enter the Engineering School at University. However, to ascertain the students’ initial knowledge of electricity and magnetism, we gave sample students from the control and experimental groups the questionnaire entitled Conceptual Survey of Electricity and Magnetism (CSEM), drawn up by Maloney et al (2001), which has been shown to be a reliable assessment tool. The results obtained showed that students’ knowledge of the area can be described as memory-based learning of concepts, laws, rules and procedures, which can be useful for them to solve standard problems and examination exercises, but does not give them sufficient comprehension to apply these concepts to different contexts and phenomena. There were no meaningful differences in correct answers between the three sample groups. We can therefore conclude that the all groups had approximately the same level of academic competence.

The treatment of electrical capacitance in the transformed course is presented in chart 1. Setting a problem (Why is it interesting to study the processes of electrical charging of bodies?) leads to establishing the objectives to be achieved when studying the sequence and this problem is defined progressively, as occurs in scientific work, and concludes with specific problems which define the common theme of the sequence.

Chart 1. “Problemized” structure of the sequence of the subject: “How are bodies charged? How can we charge them more efficiently?”

Problems sequence	Way science works which have to be learnt	Scientific explanations which have to be understood
A. What interest can there be in accumulating charges in bodies?	A. Science is interested in natural phenomena and their social implications.	

<p>B. How is a charge stored in a body?</p> <p>What is needed to charge a body?</p> <p>Does the process of charging a body have a limit?</p>	<p>B. When setting problems, science starts by positioning them and making them available for a solution.</p> <p>Become familiar with empirical observations or information on the phenomena being studied.</p> <p>Working from organising the experimental information, producing hypotheses and selecting the right strategies, draw up an initial explanatory model.</p>	<p>B. Descriptive study of charging conductive and dielectric materials</p> <p>Acquiring a preliminary conception of the task to be studied: What is the connection between the accumulated charge and the potential acquired by a body? Differentiation between the concepts of charge and potential.</p> <p>Constructing a “systemic model of difference in potential” (body, generator, medium) which explains the charging process on the basis of the work carried out to charge it.</p>
<p>C. What does greater or lesser ease in charging a body depend on?</p> <p>What happens when we charge bodies of different sizes and shapes?</p>	<p>C. Completing the explanatory model and defining new concepts</p> <p>Test the proposed model</p>	<p>C. Establishing the concept of the electrical capacity of a body as the greater or lesser facility for storing a given charge by carrying out a given task. Operational definition of electrical capacity.</p> <p>Electrical capacity is a property of a body which depends on its shape and the environment in which it is situated.</p>
<p>D. How can we increase the yield from the charging process?</p> <p>What happens when a conductor is placed near another one which we want to charge?</p> <p>What happens when different materials are introduced between the plates of a condenser?</p>	<p>D. Working from organising the computer simulations information, producing hypotheses and selecting the right strategies, working the explanatory model.</p> <p>Test the proposed model. Design and make experimental checks or use simulations.</p> <p>Evaluate the validity of the model and its limitations.</p>	<p>D. Extending the explanatory model to the case of condensers.</p> <p>Using the model explaining electrical capacity to optimize the storage of a charge in a condenser by introducing a dielectric between its plates.</p>

During the sequence students developed the following kinds of activities:

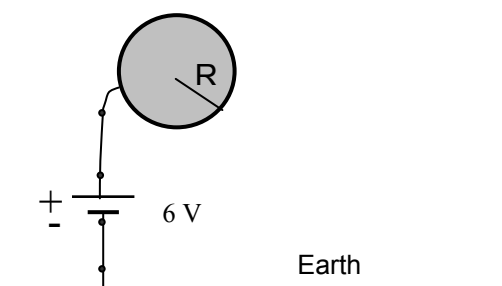
- a. *Social implications of the topic*, which tries to make the problem interesting for the students, so that they become involved in solving it and, in addition, makes them aware of the objectives being proposed.
- b. *Group work*, in which students working in small groups evaluate their individual ideas, add new ideas, and reach a consensus or disagreement.

- c. *Class discussion and teacher's guidance*, the teachers guided a question-posing approach. This approach brings students in such a position that they are able to extend their knowledge and abilities in a certain direction which contributes in solving the problem. The representative of each group presents the group's consensus; all the ways of resolution of the task are discussed, under the guidance of the teacher and a classroom summary is formulated.
- d. *Individual report*, in which each student individually accounts for the resolution of the task with specific explanation in justification of results. In the following lesson the teacher discusses students' reports.

In step B of the sequence (see chart 1), we propose to students that they could interpret the processes of electrical charging of bodies from the idea that charges only move when there is a potential difference as they learned in Electrostatics. For example, one of the tasks of this step of the sequence is the following:

Task:

Describe the process for charging a conductive sphere with radius R , connected to the positive pole of a 6 V battery, with the negative pole being earthed. Calculate the work necessary to charge the conductive sphere with charge Q . What does this work represent?



Below are some comments from students, made in the discussion session after working in groups to solve the task:

- Representative from Group 2: Electrons will pass from the battery to the sphere until no more can be accumulated or the battery is exhausted. We do not know how to calculate the work, we would have to know the power with which the electrons are thrust and the space travelled.
- Representative from Group 6: We do not agree as we have seen that the electrons move towards increasing potentials. At the start of the process there is a difference in potential between the positive pole of the battery (+6 v) and the sphere (0 v), therefore electrons pass until the potential of the sphere is +6 v. when the potentials become equal no more electrons can pass.
- Representative from Group 8: We agree with Group 6's explanation as it allows the work carried out to be calculated, whereas group 2's explanation does not. If we consider that the potential is the work carried out by the charge unit, the work carried out will have been $6Q$ joules.

Negative charges move through the wire from low potential to high potential. The 'systemic model of potential difference' prepared for the movement of electrons in a wire remains rather simple: they provide a coherent interpretation at microscopic level for the 'mechanism' of charging of bodies. Using this model, one needs to separate charges and electrical potential (energy) in order to be consistent with the end of the process of charging. Using the model we introduce the definition of electrical capacitance (step C), and the homework includes many questions asking students about different elements of the model which elicit the pertinent variables of the model by discussing the meaningful or meaningless nature of the different factors of an explanatory theory of the processes of electrical charging of bodies.

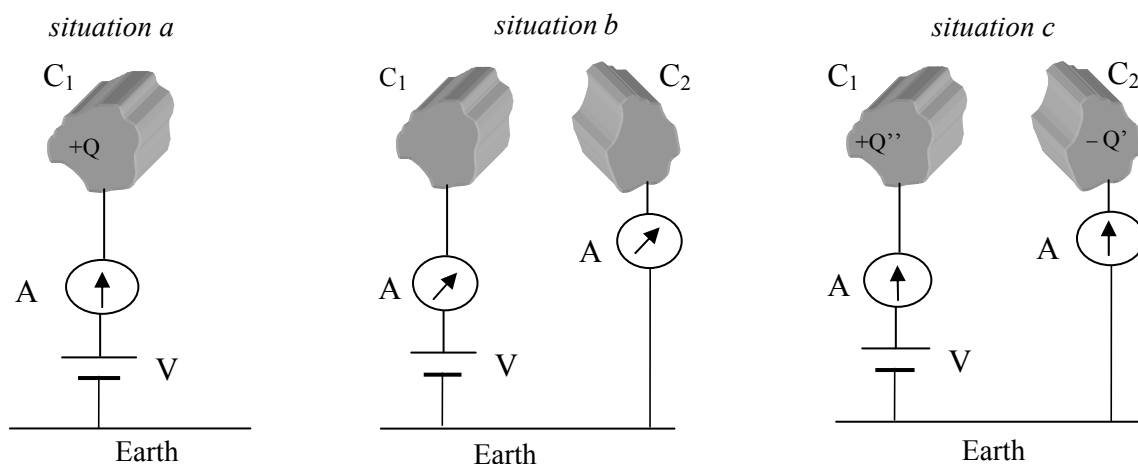
During step D of the sequence, we helped students to develop an explanatory theory that predict an improvement in the effectiveness of process of charge. The expected ways of reasoning require relationships among two bodies (one charged at least) that are close to one another, their electrical influence and the potential variation of the system. We introduced the capacitor and its electrical

capacitance. In the following example the task presents a process of charging with constant potential due to the presence of the battery:

Task:

In the figure conductor C_1 has been charged with $+Q$ by connecting it to the battery of V volts (situation a). A neutral body C_2 is brought close to it. Conductor C_2 is then earthed and it is observed that the ammeters A mark the passage of current along the wires connected to conductors C_1 and C_2 which acquire a charge $+Q' > +Q$ and $-Q'$ (situation b).

1. How do you explain this phenomenon? What has happened to the potential of body C_1 ?
2. At the end of the process, conductive charge C_2 is now $-Q'$ (situation c) How do you explain this fact? What is the potential of body C_2 ?
3. Has the capacity of conductor C_1 been changed by conductor C_2 being brought close to it?
4. Use the “Applet_two conductors” simulation to check and justify your results.



Some students’ comments from reports:

- Representative from Group 9: If there is movement by a charge in situation b) this is because there is a difference in potential between the battery and the body. This seems a contradiction because in situation a) a balance had already been reached between the potential of body C_1 and the battery. We have assumed that the potential of body C_1 may in some way, perhaps through electrostatic influence, vary body C_2 . There is a variation in potential in the system formed by both bodies and therefore a movement of charges in situation b).
- Representative from Group 10: We thought that bringing body C_2 up close somehow influences the potential of body C_1 . In some way the potential of C_1 has to decrease because otherwise there would be no movement of current in situation b). There is only a movement of charges if there is a difference in potential. We think that by grouping both bodies together we will increase the capacity of the system and more charges can be accumulated as $Q' > Q$.

The examination for this part of the course and the final examination for the course included questions about the difference between the concepts of charge and difference of potential (3 questions); about understanding the electrical capacitance (3 questions); and about the concept of electrical capacitance of a condensator (3 questions). An analysis of students’ answers is presented below.

RESULTS

We analysed students’ responses to the exam questions from each year. We are presenting in this paper the results for the second year of implementation because the second year material was transformed in some sections taking into account the experience of the first year. In the first year of implementation, we found that the sequence of problems and contents was adequate for students to learn about an energy-based model of capacitance in the processes of charging. However, students failed to understand

how on certain activities, and, basically, the general purpose of their work. Those activities were modified and sometimes eliminated towards the second year of implementation. In the second year the number of students of the two experimental classes was 88 (45 Group E1 and 43 Group E2) and 65 students as control groups (Group C, two classes).

Distinction between charge and electrical potential

From the results of research into physics education, most students analyzed the charging process in terms of the amount of charge which bodies in contact have and did not mention difference of potential. Activities in the sequence had been designed so that students built up the significance of work and energy for these processes. Firstly, how much has the sequence helped to differentiate between the concepts of charge and electric potential? To answer this question, we designed the questionnaire “Charge and potential” (see appendix). For example, in question Q3, students had to explain charging spheres in terms of the difference in potential between them and the battery. In addition, only the nature of the material of each sphere could be taken into account if reasoning is in terms of difference in potential. The figure 1 presents the results obtained from the experimental (Groups E₁ and E₂) and control (Group C) groups. The results indicate a positive effect of the sequence for using the concept of potential difference to analyse the process of charging a body.

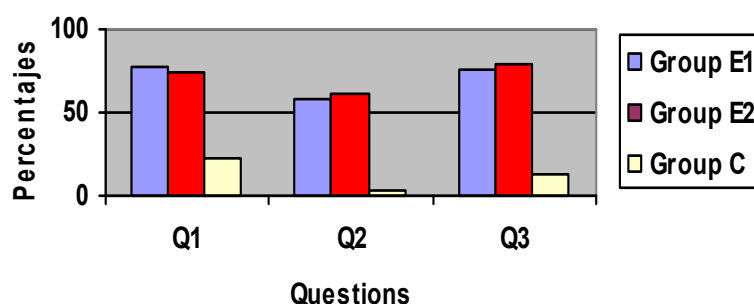


Figure 1. Percentages of correct answers on the differentiation between charge and potential

The majority students in the experimental groups refer to potential difference concept and many reasons in terms of the concept of potential. For example:

- “The sphere will be charged until the two bodies have the same potential, at which moment charge will cease to pass through the wire. Furthermore, there will be a limit for the charge of the sphere in accordance with its radius and dielectric constant.” (Question Q1)
- “It would vary, as wood is a poorer conductor than metal, and, thus, it would be charged at the contact area itself in a different way. Moreover, the charge it would accept would be lower, for carrying it would demand more work, and the power difference between both bodies would be equalled will less charge.” (Question Q2)

In contrast, the great majority of the control students reasoned in terms of amount of charge tending to become the same in the two contact bodies. In the case of an insulating body (Q2 and Q3), the majority of experimental students continue using the potential difference, but most of control students said that the movement of charges was not allowed and therefore there was no charge. Bellow we present some of the control students’ answers:

- “The sphere will be charged until the amount of charge in the sphere and in the battery are the same.” (Question Q1)
- “As plastic is an insulator, the plastic sphere will not be charged. No charge may be passed from the battery to the plastic sphere.” (Question Q3)

About capacitance

We hoped that the students studying the sequence would take into consideration the need for a new measure of the ease or difficulty presented by a body for it to be electrically charged. This meant that

students would acquire a meaning for the concept of different capacity in the concepts charge and potential. Some of the questions used to assess this point appear in the “electrical capacitance” questionnaire (Q4, Q5 y Q6) attached. The results are shown in graph 2.

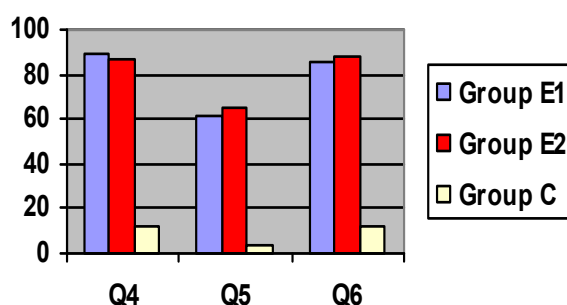


Figure 2. Percentages of correct answers on the meaning of capacitance

The great majority of students in the experimental groups considered capacity as the degree of ease with which a body stores a charge. Most of the experimental students explained the qualitative meaning of the concept of electrical capacity (Q5), although there was a significant percentage which only described the formula. An example of correct answer of question Q5 is the following:

- “The electric capacity of a conductor is the highest or lowest ease with which it stores electric charge and electric energy.” (Question Q5)

If there is a physical meaning to the concept of capacity, there is no difficulty in admitting that any body, be it charged or not, has electrical capacity. Some examples of correct answer are the following:

- “It has electric capacity in both situations, as capacity does not depend on the charge but only on the material and the geometry involved.” (Question Q4)
- “The electric capacity of a body is associated to the ease with which it is charged. Therefore, it always has electric capacity, whether it is charged or not.” (Question Q4)

In fact, the great majority of the experimental students answered the question Q4 correctly (88%), whereas the great majority of the students in the control group reasoned incorrectly. The latter students based themselves on the formula and reasoning that if the charge is zero, the coefficient between charge and potential is also zero and therefore there is no capacity.

The results of questions Q4, Q5 and Q6 were convergent and showed that the sequence has influenced the students to consider the distinction between the equation for electrical capacity and its meaning. However, there was a drop in correct reasoning when students analyzed electrical interaction phenomena in dielectrics (questions Q2 and Q5). It will be necessary to pay greater attention to this point in subsequent implementation of the sequences.

Electrical influence between close bodies and capacitors

With the aid of the sequence we hope that students will argue by considering the charging process as a system made up of bodies and the medium (systemic model) and not reason on the basis of each isolated body. This means understanding the use of condensers as suitable apparatus for increasing the effectiveness of the charging process and therefore the capacity of the system. The results of the questions on the above aspects (Q6, Q7, Q8 attached) are shown in figure 3.

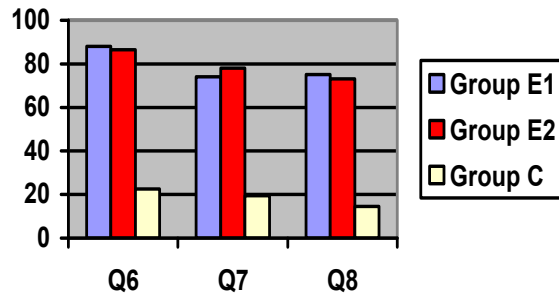


Figure 3. Percentages of correct answers on electrical influence and capacitors

The electrical influence between adjacent bodies was acknowledged by the great majority of students who followed the sequence and established a gradation in the ease of charging a body depending on the induction between bodies and its influence on the electric potential of bodies. According to this type of reasoning, three quarters of experimental students acknowledged that electrostatic induction is exerted between two adjacent bodies (with at least one of them charged) which causes the potential of the system to drop and therefore its capacity to increase. Some examples of the correct answers from the experimental group students are the following:

- “The proximity of a body A with charge $-Q$ will render the charging process easier, as a lower potential difference appears by electric induction, which makes it easier for positive charges to approach.” (Question Q7)
- “This is due to the fact that when the cylinder of radius R_1 has positive charge and the cylinder of radius R_2 is charged by induction with an equal negative charge (the student draws a correct diagram), the cylinders influence each other, which brings down the system’s potential. If we connect the outer cylinder to a generator, we will be able to charge it even more. Thus, capacity increases as the charge increases for a certain potential. The lesser the distance between R_1 and R_2 , the higher the capacity increase as a result of higher interaction.” (Question Q9)

The percentages in the experimental groups are statistically different from the control group ($p < 0.01$) in all questions. All statistics were calculated using a one-tailed Z test under the hypothesis that the treatment would lead to an increase in the conceptual understanding of electrical capacitance in the context of processes of charge a body.

CONCLUSIONS AND NEXT STEPS

The aim of this article was to design and implement a teaching sequence for the concept of electrical capacitance when charging a body. An understanding of the model which explains the related phenomena and the comprehensive use of the concepts of capacitance and electric potential is problematic for a significant proportion of students. The approach in the sequence is based on helping students establish connections between the movement of charges (micro frame) and an energy analysis of the system (macro frame). Students are helped to construct a model which gives meaning to the concepts of charge, electric potential and electrical capacitance.

Since the implementation of the sequence a considerable number of students have achieved a more satisfactory grasp of the electrical capacitance of bodies and charging processes. This seems to confirm that the aspects highlighted in the sequence are relevant to defined aims; in particular, aspects which explain charging processes in a body which include comprehensive connections between charge, electric potential and electrical capacitance. Likewise, by carrying out a systemic analysis which takes into account not only the body to be charged but also its surroundings. From this point of reference, the explanatory model provides students with a “non-accumulative vision of charging” the electrical capacitance of a system. The qualitative capacity of the model gives students a set of ideas which allows them to argue efficiently about charging processes and the electrical capacity of bodies.

This study has opened up many questions for further research. In observations by students doing homework, we have found that while many students were able to correctly answer homework questions about electrical capacitance, they seemed not to relate the processes of charging to other electrostatic concepts from previous chapters such as electric potential or electrical field. This is in sharp contrast to our observations in other parts of the course such as mechanics. For this topic, students were more able to connect kinematic and dynamic concepts and models than electrostatic ones.

We found throughout the course that students did not develop model-building skills to the degree we had hoped. Most students could describe the model, but had trouble making inferences from observations; they often memorized rather than had a clear mental picture of the model. Research by Etkina et al.(2006) suggests that scientific reasoning skills are difficult to develop without a curriculum specifically aimed at giving students practice in engaging in scientific activity. While several such curricula have been developed for Secondary physics education, little work in this area has been done in the field of electromagnetism at university level.

In response to these problems, more research is needed to determine whether and how the designing of a global electromagnetism curriculum can be used most effectively to help students to practice scientific skills and build explanatory models.

REFERENCES

Benseghir, A. and Closset, J.L. (1996). The electrostatics-electrokinetics transition: historical and educational difficulties. *International Journal of Science Education*, 18(2), 179-191.

Bransford J.D., Brown A.L. and Cocking, R.R. (1999), *How people learn: Brain, Mind Experience and School*, National Academy Press, Washintong D.C.

Etkina, E., Van Heuvelen, A., White-Brahmia, S., Brookes, D.T., Gentile, M., Murthy, S., Rosengrant, D. and Warren, A. (2006). Scientific abilities and their assessment. *Physics Review Special Topics: Physics Education Research* 2, 1-15.

Furió, C. and Guisasola, J. (1999). Concepciones alternativas y dificultades de aprendizaje en electrostática. Selección de cuestiones elaboradas para su detección y tratamiento, *Enseñanza de las Ciencias* 17(3), 441-452.

Furió, C., Guisasola J. and Almudí J.M. (2004). Elementary electrostatic phenomena: Historical hindrances and students' difficulties. *Canadian Journal of Science, Mathematics and Technology Education* 4(3), 291-313.

Galili, I. (1995). Mechanics background influences students' conceptions in electromagnetism. *International Journal of Science Education*, 17 (3), 371-387.

Guisasola, J., Furió, C. and Ceberio, M. (2008) *Science Education based on developing guided research*. In M.V. Thomase (Ed.), *Science Education in Focus* (pp.55-85). Nova Science Publisher.

Guisasola, J., Zubimendi, J.L., Almudi, J.M. and Ceberio, M. (2002). The evolution of the concept of capacitance throughout the development of the electric theory and the understanding of its meaning by University students. *Science & Education*, 11, 247-261.

Guisasola, J., Zubimendi, J.L., Almudí, M. and Ceberio, M. (2007). Using the processes of electrical charge of bodies as a tool in the assessment of university students' learning in Electricity. In R. Pintó and D. Couso (Eds.), *Contribution from science education research* (pp.225-236). Springer, Dordrecht, The Netherland.

Guruswamy, Ch., Somers, M.D. and Hussey, R.G. (1997). Students' understanding of the transfer of charge between conductors. *Physics Education*, 32(2), 91-96.

Maloney, D.P., O'kuma, T.L., Hieggelke, C.J. And Van Heuvelen, A. (2001). Surveying students' conceptual knowledge of electricity and magnetism. *Phys. Educ. Res., American Journal of Physics Suppl.*, 69(7), July 2001, 12-23.

Meheut, M. and Psillos, D. (2004). Teaching-learning sequences: aims and tools for science education research, *International Journal of Science Education* 26(5), 515-535.

Mulhall P., Mckittrick B. and Gunstone R. (2001). A perspective on the resolution of confusions in the teaching of electricity. *Research in Science Education*, 31, 575-587.

Park, J., Kim, I., Kim, M. and Lee, M. (2001). Analysis of students' processes of confirmation and falsification of their prior ideas about electrostatics. *International Journal of Science Education*, 23(12), 1219-1236.

Psillos, D. (1998). Teaching introductory electricity. In A. Tiberghien, E.L. Jossem and J. Barojas (Eds.), *Conecting Reseach in Teaching in physics education with teacher education*, International Commission on Physics Education. <http://www.physics.ohio-state.edu/jossem/ICPE/BOOKS.html>

Thacker, B.A. Ganiel, U. and Boys, D. (1999). Macroscopic phenomena and microscopic processes: Student understanding of transients in direct current electric circuits. *Physics Education Research (A supplement to the American Journal of Physics)*, 67(7), S25-S31.

Tipler, P.A. and Mosca, G. (2004). *Physics for scientist and engineering*, W.H. Freeman and Company, New York.

Viennot, L. (2001). *Reasoning in Physics, the Part of Common Sense*, Kluwer, Dordrecht.

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APPENDIX

1. Questionnaire “Charge and electrical potential”

Q1. A metal sphere is connected to another body charged by means of a metal wire. Thus:

- The sphere will accept the charge indefinitely until the charge from the other body is exhausted.
- A time will come when the sphere will accept no more charge, even though the other body is still charged.
- Another possibility.

Q2. If the sphere in the above question were made of wood, would there be any variation in the charging process?

Q3. Two spheres, one metal and the other plastic, with the same radius, R , are connected separately (see diagrams) to a 15-volt generator. Which will receive the greatest charge? Why?



2. Questionnaire “Electrical capacitance”

Q4. Consider one and the same conductor in two different situations:

- its net charge is nil. Does this conductor have electrical capacity?
- its net charge is positive $+Q$. Does this conductor have electrical capacity?

Q5. Explain what the electrical capacity of a conductor means to you. Is there any sense in speaking of the capacity of an insulant?

Q6. Consider the same conductor in two different situations:

- it is surrounded by air

b. it is submerged in oil

Reason as to whether the electrical capacity of the conductor is greater, less or the same as the capacity of the conductor in oil.

3. Questionnaire: "Capacitor"

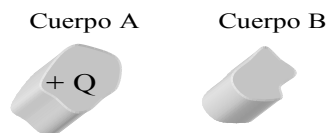
Q7. Let us consider a conductor A with charge $+Q$. When will it be easier to continue charging it and increase its charge?

- When it is insulated
- When another conductor A' charged with $+Q'$ is brought up close to it
- When another conductor A' neutral is brought up close to it
- When another conductor A' charged with $-Q'$ is brought up close to it

Q8. A body A has a net positive charge Q and another body B is brought up close to it. Due to the presence of B, will the capacity of A increase, decrease or remain the same, if:

- B has a positive net charge q .
- B has a negative net charge q .
- B has a zero net charge.

Justify your answers in each case



Q9. It is well known that a cylindrical conductor shell with a radius R_1 has less electrical capacitance than a system made up of the same shell surrounded by another hollow cylindrical conductor with a radius $R_2 > R_1$. What do you think this may be due to?