Exploring the Emotions in Pedagogical Content Knowledge about the Electric Field

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The objective of this study was to characterize the changes in the Pedagogical Content Knowledge (PCK) about electric fields of two Colombian physics teachers (Isabel and Alejandro) at the high school level (pupils of ages 17-19), and the emotions that emerged during the process of their analysis of their PCK. The research was conducted during two consecutive years, before and after their participation in a process of innovation on teaching electric fields. The method proposed corresponds to the descriptive type of case study. The PCK-related categories were grouped into two basic tendencies – traditional teacher-centred (TT) and constructivist pupil-centred (TC) – plus an intermediate tendency (TI). The results indicated that, for Isabel, the PCK components that show the greatest progression over time are curricular knowledge and teaching strategies, evolving from a teacher-centred PCK to another which does not have a defined tendency. Alejandro, whose starting point was a PCK corresponding to an intermediate tendency in curricular knowledge, was less willing to change, especially with regard to his knowledge about teaching strategies. Finally, the causes of both the positive and the negative emotions are mostly related to the curricular knowledge and the content being taught.

Keywords: word; Pedagogical Content Knowledge, Emotions, Teaching the Electric Field, High School Teachers.

Introduction

Following the model of Magnusson et al. (1999), the vast majority of studies consider the Pedagogical Content Knowledge (PCK) of science teachers to have five components: orientations and conceptions about science teaching, curricular knowledge, knowledge about pupils' learning and ideas, teaching strategies, and evaluation.

Good teachers, apart from excelling for their cognitive abilities, teaching strategies, and effectiveness in achieving assertive learning, are full of positive attitudes and emotions towards themselves, their work, and their pupils which facilitate their

process of teaching. Recent studies include the affective domain among the components describing PCK, as expressed in: emotions towards the content being taught, teaching and learning, attitudes, and teaching effectiveness (Garritz, 2010; Authors, 2014).

The objective of our study was to characterize the changes in the PCK of two Colombian physics teachers (Isabel and Alejandro) at the high school level (pupils of ages 17-19), and the emotions that emerged during the process of their analysis of that PCK. The study was conducted over two consecutive years, before and after their participation in a process of innovation in the teaching of electric fields. We therefore assume that both the affective domain and the base knowledge that makes up the PCK are transformed and integrated into the processes of innovation and professional development on specific content.

The nature and development of PCK

PCK is one of the important topics of current science education research. According to Shulman (1986), teachers develop this knowledge to help others learn. They construct it while they are teaching content specific to their area of expertise (Abell, 2008).

From our perspective, PCK is dynamic knowledge with its own structure, sources, components, nature, and filters. In addition, PCK enables and legitimises teaching as a profession. It is a meeting point between teachers' classroom practice and the knowledge they acquire through their training and experience (Alonzo and Kim, 2015; Nilsson, 2008).

Shulman (2015) and Alonzo and Kim (2015) note how classroom practice has been forgotten in many PCK studies. Alonzo and Kim (2015) highlight the need to differentiate, when measuring the PCK, the dynamic from the static aspects. They define dynamic PCK as that related to classroom practice and the reasoning underlying

their decision making during instruction, and static PCK as that related to what teachers state about teaching specific content. Dynamic knowledge is practical, acquired from personal teaching experiences in specific contexts, and evolves by means of a process of reflection-action about the practical teaching of specific material (Author, 1998).

In our case, and in accordance with what was stated by Alonzo and Kim (2015), we consider that PCK can be characterized on three levels: declarative, design, and action. These correspond to what the teacher thinks, plans, and does in teaching some specific content. We consider that the coherence of these three levels and their permanence over time are indicators of the process of transformation and integration of professional knowledge.

Van Driel et al. (2014) suggest that, for the development of PCK, opportunities should be provided for the teachers to plan, design, and evaluate their teaching with methods that include collaborative work, in addition to providing them with opportunities to share and critically evaluate the different aspects of PCK. However, it is necessary to bear in mind that each teacher will expand their PCK in a particular and personal way that depends on the content that they teach.

The emotions and teachers

The study of the emotions is not a new topic in science. Darwin addressed the subject in 1872, noting that the emotions form part of our evolutionary structure – that they play an adaptive function of the organism to our environment, have been important in the survival of our species, and are not always controlled by logic. Nevertheless, the emotions have been excluded from research for many years, being identified as improper and irrational since they are opposed to the objectivity of science. This situation has changed in recent years, and now the emotions form part of the educational research agenda (van Veen and Lasky, 2005) because teaching ultimately involves

interaction with others, and hence emotions. In a recent review, however, Uitto et al. (2015) note the paucity of research in the last thirty years addressing teachers' emotions when teaching specific content.

Science education research has had a particular focus on the cognitive factors involved in teaching and learning different topics of science, neglecting the affective and emotional domains (Garritz, 2010; Authors, 2014; Sutton and Wheatley, 2003; Zembylas, 2007). But, starting out from the initial line of attitudes, the study of the emotions in teaching and learning science has been finding its way into conferences and journals, and studies focused on this topic are becoming ever more frequent (Abrahams, 2009; Bellocchi et al., 2013; Dávila et al., 2015; Dos Santos and Mortimer, 2003; King et al., 2015; Ritchie et al., 2011; Schutz and Zembylas, 2011; Vázquez and Manassero, 2007; Zembylas, 2007).

Atkinson and Claxton (2002) note that teachers unconsciously construct an array of emotions, both positive and negative, which today is considered to be one of the profession's ways of knowing. Emotional regulation is a functional component of learning how to teach science (Oosterheert and Vermunt, 2001) and how to be more effective as teachers in handling the discipline itself and in the relationship with their pupils (Sutton, Knight and Mudrey-Camino, 2009). These same authors, however, observe how difficult teachers find it to regulate and manage their own emotions. Brígido et al. (2013) and Borrachero et al. (2014), in their research with prospective primary and secondary teachers, respectively, note that these students' recall of the emotions they felt towards different science subjects when they themselves were pupils in secondary school is transferred to the emotions they feel as teachers when teaching those subjects.

The emotions transmitted by teachers in their classes influence their pupils' learning. The study of Aydogan et al. (2015) showed that the brain activity of undergraduate science students, measured by electroencephalography, is influenced by the teacher's emotions: the students' level of attention and of meditation is much higher when the teacher transmits emotions of happiness rather than of anger.

PCK and the affective domain

Shulman (2015) notes that the initial formulation of PCK was devoid of emotion, affect, feelings, and motivation. Nonetheless, the affective aspects of the understanding and practice of teaching are important because much of what teachers know and do is connected to their own emotional states, and then influences their pupils' learning. At the PCK Summit in Colorado Springs, USA, during a public presentation, Shulman (2012) admitted that overlooking the affective part was one of the weak points of the first articles he had published on PCK:

> The first limitation is that PCK as I originally conceived it was devoid of emotion, affect, feelings, and motivation, all of the non-cognitive attributes. It also gave short shrift to the moral character of teaching, an aspect of my work that so annoyed one of my former teachers, Philip Jackson. I was so intent on combatting the missing paradigm of content that I did not devote attention to affect and motivation, nor to moral judgment and reasoning in teaching. This is such an important missing piece. The affective aspects of teacher understanding and action are important both because a lot of what teachers "know and do" is connected to their own affective and motivation states, as well as their ability to influence the feelings, motives, persistence, and identity formation processes of their students. All of this is also related to their normative vision for the kind of world to which they aspire to contribute as professional educators and as citizens in democratic society. (Shulman, 2012, quoted in Berry, Friedrichsen & Loughran, 2015, p.9).

Although not always explicitly, affective aspects have been present in various PCK related studies. Some examples of this are the studies which indicate that teachers do

not easily change their conceptions, and much less their teaching practices, if the changes do not help to give them personal satisfaction at work and compensate them affectively (Tobin, 1998; Verjovsky and Waldegg, 2005). Padilla and van Driel (2012) concluded that research on the teachers' conceptions of science should pay more attention to their emotional knowledge and interaction with their pupils, as well as to the influence of affect on teachers' professional development.

For Zembylas (2007), emotional knowledge is an important part of PCK because teachers connect their emotions with what they know about the content, with the pedagogy, with the discourse they take to the classroom, with the curriculum, and with their personal histories. McCaughtry (2005) also stresses that emotions should be included in PCK, although just those related to specific content. Garritz (2010) and Padilla and van Driel (2012) suggest the need to recognize the affective domain as a component of the model of Magnusson et al. (1999) so as to ensure its inclusion in the analysis of PCK. Other authors however (Gess-Newsome, 2015; Authors, 2014; van Driel et al., 2014), consider the affective domain as being the catalysing lens of teachers' cognition and action, fulfilling different functions: as the source of PCK, mobilizing the knowledge of the discipline, a part of psychopedagogical and educational knowledge, and as an element that sets the guidelines for teaching the sciences.

We consider that the affective domain is not only a catalyst but also a necessary condition for the teaching and learning process to occur. However, there is a lack of tools to show the kind of relationship between affectivity and PCK. Therefore, it was our intention in this study to determine the emotions that emerge in the process of analysis of the PCK components of Magnusson et al. (1999).

Overview of the study

This study focuses on the characterization of the PCK declared by teachers about teaching the electric field, and the emotions that emerge in the process of analysing the PCK during two consecutive academic years (2010/11 and 2011/12). Consequently, the objectives are:

(1) To describe the PCK on electric fields as declared by two physics teachers during two consecutive courses before and after they had participated in a process of innovation on teaching the electric field.

(2) To characterize the emotions that emerge from the process of analysing the PCK.

Methods

Participants

The participants in the research were two high school physics teachers in Colombia whom we shall refer to with the assumed names Isabel and Alejandro. This choice was made to allow the assumption to be made of similar teacher preparation with respect to relative emphasis on content and pedagogy (Author, in press). When we began the study, Isabel was 28 years old, was working in a private girls' school, and had five years of teaching experience in secondary education and two years in high school. Alejandro was 30 years old, and had seven years' experience teaching physics in high school and one year in primary teacher education. He had worked for the last four years in a boys' school. Their pupils ranged from 17 to 19 years old. They taught groups of from 15 to 30 pupils.

Data Collection

We acquired the data with: (a) a semi-structured interview to investigate the teachers' PCK on electric fields; (b) an open-ended questionnaire on what the teachers considered to be the strategies in physics teaching and the role of planning in the teaching and learning process; and (c) the matrix (CoRe) designed by Loughran et al. (2004) to represent the content.

The instruments were rated by four university lecturers (two Spaniards and two Colombians), experts in science education and teacher training, who contributed to the wording and structure of each instrument.

Open-ended questionnaire: The questionnaire was given in August 2010 and 2011, before teaching electric fields (Author, in press). The intention with this instrument was to explore what the teachers think about the instructional strategies they use in their physics classes when teaching electric fields, and the ideas behind their curricular design. For the design, we chose open questions because our intention was to obtain varied and comprehensive answers, without conditioning or predisposing the teachers about the teaching of electric fields.

Semi-structured interview: The semi-structured interviews were conducted in February 2011 and 2012, after teaching electric fields. The interview questions were based on the literature about PCK with science teachers and on research about teaching electric fields. The interviews were carried out in private in a place chosen by each teacher. All the interviews were audio-recorded and transcribed verbatim for subsequent analysis. They were focused on: the reasons that led them to choose teaching, their ideas about how their previous experience might influence their actions and the decisions they make

when planning, the pupils' knowledge, content, methods, evaluation of the learning, and curricular knowledge.

Content representation matrix (CoRe): The CoRe matrix has-been used to evaluate multiple aspects of teachers' knowledge, including content knowledge. The CoRe tool is a table consisting of rows and columns that have to be related (Loughran et al., 2004). Each column has a central idea of the specific topic being asked about. These central ideas present an overview of what each teacher wants to teach. The rows contain various questions related to the components of PCK. This instrument was completed in January 2010 and 2011 before teaching electric fields.

Data Analysis

The systematization and analysis of the data was conducted following the techniques of content analysis, supported by the Nvivo-10 software package. Categories were established for the four elements of PCK: (i) curricular knowledge; (ii) knowledge of pupils' understanding of science; (iii) knowledge of representations and instructional strategies; and (iv) knowledge of evaluation. These categories were tested on the 2010-11 and 2011-12 data collections. As a result of this test, some categories had to be reformulated, and thus emerged the categories related to emotions.

The categories related to PCK were grouped into the traditional teacher-centred tendency (TT), the constructivist pupil-centred tendency (TC), and an intermediate tendency (TI). In carrying out this classification, we considered the descriptions given by the models of teaching in the didactics of experimental sciences (Domingos-Grilo et al., 2012; Schneider and Plasman, 2011; among others). The results were presented together to three expert researchers to confirm the relevance and reliability of the description. The final codebook is summarized in the Appendix.

To classify the codes related to the emotions, we analysed the explicit descriptions that the teachers gave of on their tendencies of action, and the evaluations of the situations they had experienced. Table 1 lists the sources that were considered in characterizing each teacher's emotions when teaching electric fields. In all cases, a distinction was made between positive and negative emotions. This classification was carried out following the parameters established in previous research with teachers in primary and secondary education by Borrachero et al. (2014) and Brígido et al. (2013). Some of the positive emotions are: satisfaction, confidence, capability, security, friendliness, etc. Some of the negative emotions are: worry, anxiety, stress, frustration, uncertainty, boredom, etc.

Table 1. Categories to characterize the emotions towards teaching the electric field.

E1. Content	E2. Curriculum and methods	E3. Relationship with the pupils	E4. Relationship with the context
Encompasses the emotions they declared to be a result of experiences related to the content, from their beliefs, experiences as students, planning, and classroom practice.	Encompasses the emotions declared to be about situations involving evaluation, the pattern of the topic, and methods and teaching strategies related to charge, force, and electric field.	Response to situations, attitudes, and emotions of pupils faced with the implementation of the teaching unit and the management of the class during the teaching of the electric field.	Encompasses the emotions declared to be a result of institutional requirements and social demands, and their coherence with the teacher's conceptions.

Results

Table 2 summarizes the dominant tendencies of Isabel's and Alejandro's PCK during 2010-11 and 2011-12. In each category, we identified the dominant tendency from the number of codified information units. We assigned the mixture of tendencies (O) when the frequency of information units was similar among the three tendencies (traditional-TT, intermediate-TI, and constructivist-TC), or with only minor variations of up to 5%.

Table 2. Predominant tendencies of the PCK.

		ISABEL		ALEJANDRO	
PCK components	**Categories**	**2010-11**	**2011-12**	**2010-11**	**2011-12**
A. Knowledge of the curriculum concerning electric fields	A1. Content and selection criteria	TT	O	TI	TI
	A2. Organization of the content	TT	O	TI	TI
	A3. Sources and resources	TI	O	TI	TI
	A4. Objectives	TC	TI	TT	O
B. Pupils' knowledge when learning the electric field	B1. Nature of the pupils' ideas	TC	O	TC	TC
	B2. Learning difficulties	TT	O	TT	O
	B3. Participation	TT	TT	TT	TT
C. Knowledge of evaluation for the electric field	C1. Object and purpose of the evaluation	TT	TT	TC	TT
	C2. Who participates in the evaluation	O	O	O	O
	C3. Type of evaluation instruments, techniques, and design	O	O	O	O
	C4. Grading	TT	TT	TT	TT
D. Knowledge of teaching strategies on the electric field	D1. Strategy selection criteria	TC	O	TC	TC
	D2. Type of strategies and activities	TT	O	O	O
	D3. Teaching sequence	TT	O	TT	TT

TT: traditional tendency; **TI:** intermediate tendency; **TC:** constructivist tendency; **O:** the three tendencies emerge equally.

In the table, the categories in which a progression occurs are shaded in light gray: there was a change from a traditional to an intermediate tendency, from a traditional to a mixture of tendencies, or from a mixture of tendencies to an intermediate one. The categories in which a regression occurs are shaded in dark gray: a change from a mixture in tendencies or an intermediate tendency to a traditional one and from a constructivist tendency to a traditional one.

For Isabel, the PCK components that had the greatest progression over time were curricular knowledge and teaching strategies. This teacher went from a PCK more focused on herself to another that was a mixture of different tendencies, and therefore less defined. The 2010-11 academic year was characterized by starting from a simpler theme (electric charge) to a more complex one (electric fields). During the 2011-12 academic year, she modified the structure of the content, depending on her pupils' learning, and she considered that the idea of electric force, as an effect of the field, is the key to constructing the concept of electric fields. However, the changes in the

organization of the content made her feel insecure, which led her to rely more on the textbook for support. In the teaching strategies, she initially declared conceptions close to a constructivist tendency, noting the active role of the pupils in the process of learning about electric fields. These ideas are not, however, reflected in the description made of the teaching sequence and the activities used in class which corresponded more to the traditional tendency. In the second year, she showed a mixture of tendencies in the selection of strategies, but in the classroom she showed progression in both the teaching sequence and the type of strategies and activities. For example, she proposed strategies related to everyday life that allow the pupils to move from the abstract to the simple. She also implemented a new sequence of teaching that involved the pupils doing experiments, followed by debates for them to discuss, defend, and validate their results.

Isabel showed no changes in the evaluation component, the objective of which is to check what is taught as measured by the level of understanding that the pupils demonstrate when applying what they have learned.

Alejandro showed less willingness to change than Isabel. His starting point for the curricular component of the PCK was of an intermediate tendency, and only showed changes in the objectives. During the first year, solving exercises about Coulomb's law and the electric field intensity was the cornerstone of his objectives. In the second year however, he considered that the true intention of his teaching was to show that physics is much more than applied mathematics. Alejandro followed two possible routes for the order in which to teach the concepts, depending on the evaluation of his pupils' skills and prior knowledge, although he always started with the electric charge and finished by teaching circuits: (1) the concept of electric force precedes the presentation of the concept of field, and (2) potential and the idea of field precede the presentation of the

concept of force. The only category that showed changes in the component of the PCK on pupil knowledge was that of learning difficulties and their causes. During the first year, he only referred to the level of abstraction of the content, and to generic difficulties that are applicable to any curricular content. In the second year, he recognized specific difficulties with the content that he later was able to relate with his analysis of different episodes in his classes.

In the evaluation, he showed a regression in the objective from a constructive tendency to a traditional one. During the first year, his evaluation process was continuous, and allowed him to identify the pupils' achievements and difficulties. In the second year however, he described an evaluation that had the function of checking the content that had been learnt. We detected no changes in the teaching strategies. The basic sequence was: the teacher explains, the pupils apply, and the teacher evaluates.

Emotions that emerged during the analysis of the PCK

In the following, we shall present the emotions described by the two teachers from the analysis of their PCK and based on the categories described in Table 1. We shall finish by showing the relationship between the emotions and the content being taught.

Emotions declared by Isabel

Figure 1 shows the causes of the emotions towards teaching electric fields expressed by Isabel. In 2010-11, a total of 134 units of information were classified, and in 2011-12 a total of 157. The first cause of both the positive and negative emotions was in reference to the curriculum (E2), followed by the content, relationship with the pupils, and relationship with the context.

Figure 1. Causes of the emotions declared by Isabel.

=== FIGURE 1 ABOUT HERE ===

In the first year, the positive emotions, such as satisfaction, capability, and security due to content (E1), referred to the confidence the teacher had in her knowledge about the definition of charge and Coulomb's law. Isabel also expressed satisfaction with the use of experiences related to lines of force and with all the experimental activity because these had helped her to better understand the content when she was at university, and also allowed her to demonstrate the truth of what she explained. Negative emotions such as frustration and anxiety alluded to the difficulties the teacher had faced in mathematics during her university years. This led her to consider mathematics as being a tool for physics. In the second year, the positive emotions referred to the reflections she made during the innovation process on understanding the concepts of field and electric force. However, these reflections were also the cause of an increase in negative emotions, especially because of her insecurity in her epistemological reconstruction of the content to be taught.

The frequencies obtained for the positive and negative emotions caused by the curriculum and methods (E2) show few changes. The reasons the teacher gives for her emotions are: (i) the satisfaction and concern experienced because of the new organization of the content in which force is presented as the cause of the field, and a teaching sequence that links more magnetic examples than mechanical ones; (ii) anxiety, disappointment, and frustration with the results of the pupils' evaluation and the lack of time to propose pupil-centred actions; and (iii) the satisfaction and concern with the image of an effective teacher that she projects by the actions and decisions she took during her teaching of electric fields. In this regard, the teacher said:

> […] one expects to see it and not to be told about it (referring to field lines), but I feel that it is gratifying for the girls, and they tell me, "It is that I love you to show

> us, and that you do experiments for us, and that's exciting." And it may be the simplest of experiments, but they understand things differently. For example it is one thing to say that the field is a disturbance that travels through space and another thing is to get them to look and see. They love that, and I am happy too because I feel I'm not lying to them. [Interview, 2011]

The positive and negative emotions caused by the relationship with the pupils (E3) had similar distributions in the two years. The positive emotions were related to the pupils' response to solving problems about the superposition of electric fields and forces, and the explanation of electrostatic phenomena. The negative emotions were due to her pupils' attitude during class. Isabel considered that they did not value her work and the time spent in the design of her classes, which then makes her opt for a traditional mode of teaching, as in the following quote:

> […] the difficulty lies more in the attitude that they take, that they never saw anything. They forget everything, even what you told them in the previous weeks or months, they do not remember and facing that is very difficult, but typical during this course. I am very sad to admit it, it is very difficult, because I knew them to be very willing, very thirsty to learn, and now they do not want to know anything, and I have no other choice than to fight against this. [Interview, 2011]

Finally the emotions related to context (E4), which had the lowest representation of all the causes, were mostly positive. They referred to the satisfaction Isabel feels for the support she receives from the school in developing her teaching, which gives her greater confidence to deal with the challenges of her everyday work.

Emotions declared by Alejandro

Figure 2 shows the causes of the emotions expressed by Alejandro towards teaching electric fields. A total of 183 information units were classified in 2010-11 and 91 in 2011-12. As was the case for Isabel, the first cause of both the positive and negative

emotions was in reference to curriculum and methods, followed by content (especially for the positive emotions in the second year), the relationship with the pupils, and the relationship with the context.

Figure 2. Causes of the emotions declared by Alejandro.

=== FIGURE 2 ABOUT HERE ===

The positive emotions related to content (E1) in the first year were mostly linked with electric charge and electrification phenomena, as they are the contents that Alejandro most enjoys teaching and considers that he understands best. The negative emotions, such as pessimism, disappointment, and boredom, were focused on the electric force and the mechanistic vision of physics, and were the result of his own experiences as a student and the teaching sequence that he follows, which makes his pupils consider mechanics to be difficult and boring. In the second year, there was an increase in the positive emotions and a major decrease in the negative ones. Unlike the first year, the positive emotions were linked to the idea of the electric field. The most frequently named were capability, satisfaction, confidence, and sympathy, and referred to what he knows and wants his pupils to learn. The negative emotions, such as frustration and disappointment, continued to refer more to the content of Newtonian mechanics and less to the content of electrostatics.

During both years, the curriculum and methods factors (E2) were those that caused most positive and negative emotions, although Alejandro's changes on the curricular component were not comparable to those reported by Isabel. This is due to his high degree of satisfaction with his curricular designs for teaching electric fields during the first year. The emotions were also related to practical activities in which

explanations are created. However, the frequency of positive emotions fell considerably in the second year, when we suggested that the teacher position himself on a route of specific content (force as effect of the field) and to express his ideas in explicit planning, going beyond merely mental planning. In both years, the negative emotions were related to the decline in motivation of his pupils due to the strategies used in class. Examples of this are:

> […] The idea is that they get fond of the things and see their usefulness, and do not do them because of obligation. This is quite difficult, and finding strategies for it is complicated. I think you should start with examples and simple demonstrations. For example, in electrostatics, starting with the Van der Graff [sic] generator they like a lot, and they tell me, "that's cool!", and ask me to show applets or virtual demonstrations about it, and that can be a starting point, "Why does lightning strike down to the ground?", and I tell them that they know that lightning does not only strike the ground but also a small amount comes up from the Earth, this also starts to motivate them, and me too. [Interview, 2011]

> […] I feel a bit frustrated with the difficulty of finding activities to develop the theme, and it is more complicated. I lack ideas to represent electric fields, it is also very difficult to plan activities that let them understand the concept of force in a simple way so that it is not confused with field. [CoRe, 2011]

The emotions caused by the relationship with the pupils (E3) were mostly negative. During both years of the study, Alejandro insisted that the negative emotions were due to the teacher's attitude in class and the organization of the physics laboratory, because the pupils were always organized into groups. This is an invitation to disorder, so that discipline and control of the class are a constant problem, as exemplified in the following:

> […] it is maddening to see that there are pupils who are doing nothing and are starting to bother the class, perhaps because of that organization, and it is

frustrating after the amount of time I spend in preparing things. I think that this is one of my weaknesses. I do not know how to improve it. [Interview, 2011]

Finally, the emotions referring to the teacher's context (E4) had little representation, and the description did not differ from that given by Isabel.

Relationship between emotions and content

As we analysed the causes of the emotions, we detected that the emotions did not occur in the abstract, but were related to specific content. These results are summarized in Table 3. They suggest to us that the positive and negative emotions are not distributed among the content in the same way during the two years of research. The percentages are calculated on the total number of information units for each year.

Table 3. The declared emotions about teaching specific content.

	ISABEL				ALEJANDRO			
	2011 N=134		2012 N=157		2011 N=183		2012 N=91	
Content and its teaching	*Positive emotions %(n)*	*Negative emotions %(n)*	*Positive emotions %(n)*	*Negative emotions %(n)*	*Positive emotions %(n)*	*Negative emotions %(n)*	*Positive emotions %(n)*	*Negative emotions %(n)*
1. Electrification of matter	9.0% (12)	6.0% (8)	9.6% (11)	6.4% (10)	12.0% (22)	3.3% (6)	12.1% (11)	-
2. Definition of electric charge	4.5% (6)	-	8.3% (13)	3.8% (6)	14.8% (27)	-	12.1% (11)	-
3. Definition of electric force - Coulomb's law	6.0% (8)	-	3.8% (6)	-	-	5.5% (10)	8.8% (8)	-
4. Superposition of electric forces	9.0% (12)	14.2% (19)	5.7% (9)	3.8% (6)	5.5% (10)	4.4% (8)	9.9% (9)	6.6% (6)
5. Definition of electric field	4.5% (6)	6.0% (8)	5.7% (9)	5.1% (8)	7.1% (13)	6.6% (12)	11.0% (10)	6.6% (6)
6. Superposition of electric fields	4.5% (6)	6.0% (8)	5.7% (9)	3.8% (6)	-	5.5% (10)	7.7% (7)	5.5% (5)
7. Electric field lines	11.2% (15)	-	12.1% (19)	5.1% (8)	12.0% (22)	-	-	6.6% (6)
8. Difference between field and electric force	4.5% (6)	6.0% (8)	7.0% (10)	5.1% (8)	-	5.5% (10)	-	6.6% (6)
9. Relationship between electrostatics and electrokinetics	9.0% (12)	-	-	8.9% (14)	14.8% (27)	3.3% (6)	6.6% (6)	-
Total	**61.9%** (83)	**38.1%** (51)	**58.0%** (91)	**42.0%** (66)	**66.1%** (121)	**33.9%** (62)	**68.1%** (62)	**31.9%** (29)

For Isabel during the first year, there was content that only aroused positive emotions in her. Examples are the content referring to field lines, the relationship between electrostatics and electrokinetics, and the definitions of force and electric field. For the

remaining content, except for the electrification of matter, she stated that she had more negative emotions than positive ones, with the superposition of electric forces being that which aroused the most negative emotions. This situation changed drastically in the second year for the content related to charge, force, and field, for which she said she had experienced both positive and negative emotions. Unlike the first year, the relationship between electrostatics and electrokinetics only generated negative emotions for her since, during the innovation process, she did not know how to connect that process with the planned actions. On the other hand, force lines still represented the content that aroused most positive emotions for her, because it is content that allows her to exemplify her teaching objectives.

Alejandro experienced a slight increase in the percentage of positive emotions from one year to the next, despite presenting only minor changes in his PCK, and this was mainly due to his understanding of the content. In the first year, content such as electric force, superposition of the electric field, and the difference between field and force only inspired negative emotions in him. Force lines, however, only generated positive emotions in him, as had been the case for Isabel, followed by the content related to the definition of electric charge, and the relationship between electrostatics and electrokinetics. In the second year, as he decided to present force as an effect of the field, the definitions of field and electric force generated more positive than negative emotions for him, whereas lines of force only generated negative emotions. This was due to alternative ideas that the teacher detected about his knowledge of the content, in which he tends to affirm, in all cases, that the path followed by a free particle in an electric field coincides with the line of force. Finally, the content that still only evoked negative emotions was the relationship between force and electric field, and was related

to the lack of effectiveness that the teacher experienced in getting his pupils to differentiate between the field vector and the force vector.

Discussion and Conclusions

Regarding the first objective, the results show that the teachers each developed their PCK in a particular and personal way, that the changes occurred slowly and gradually, and that they affected some components of PCK more than others. There was a major change in Isabel's PCK. She had taught high school for less time than Alejandro, with curricular knowledge being the component which changed most over time, followed by knowledge of teaching strategies, and knowledge about the pupils. As a result, Isabel went from a more teacher-centred PCK to an eclectic PCK that was a mix of tendencies. Alejandro's starting point was a PCK describing curricular knowledge centred on an intermediate tendency. He was less willing to change, especially with regard to his knowledge of teaching strategies and participation which were teacher-centred.

Comparing the cases of Isabel and Alejandro, we found that opting for a sequence of the content in which the electric force is presented as the effect of the electric field has a direct influence on deepening the teacher's knowledge about pupils' difficulties. The reason is that the information which results about the pupils' difficulties allows them to clarify the difference between force and field, and to identify their own alternative ideas about the content. In this respect, Henze et al. (2008) and Kind and Kind (2011) consider that the lack of identification of learning difficulties is due to the lack of knowledge of the content being taught. Sadler et al. (2013) indicate also that possessing an education in physics does not guarantee being able to recognize the learning difficulties that pupils may have. In their review of PCK, van Driel et al. (2014) note how most research indicates that teachers have just a limited knowledge of their students' understanding and learning.

The PCK component related to evaluation changed the least from one year to the next. This is due more to the teachers' perception about what they can do in the classroom than to their own beliefs about evaluation, and to a lack of integration with the other components of their PCK. Lee and Luft (2008) conclude in their study that the reason for the lack of importance given to evaluation is due to knowledge about resources not forming an integral part of PCK. For Ogan-Bekiroglu (2009), this is due to the beliefs of self-efficacy about the ability to evaluate others, and knowledge of effective methods of evaluation.

With respect to the second objective, we found that the characterization of the PCK is full of emotions that are related to knowledge about the curriculum and methods, the relationship with the pupils and with the context – elements of the PCK that depend on the content being taught. In the case of Isabel, the combination of positive and negative emotions towards the curriculum, methods, and content catalysed her changes. Alejandro however, during the first year, showed many positive emotions about the curriculum and methods. This made him feel satisfied and happy with what he was doing, and therefore he did not need to change.

Professional development has to go together with personal and social development (Bell and Gilbert, 1994), taking affective aspects into account. As noted by Day (1999), change is not just a matter of the head, but also of the heart. It will be difficult to put changes into effect unless they are compensated affectively and contribute to greater personal job satisfaction. Change implies recognizing that something can be done better than it is being done at present. Elliot (1993), from an action research standpoint, considered that an essential condition for teachers to initiate a process of change in their educational practice is that they learn to control and tolerate a certain loss of self-esteem.

Excessive negative emotions, without viable alternatives, may lead the teacher to paralysis, frustration, and burn-out. Positive emotions too, however, may lead them to a comfort zone which can also hinder change. In our study, a combination of positive and negative emotions had most potential for change.

For Isabel, this situation was constant from the beginning of the study, and continued through the second year. This suggests that she will continue to seek new strategies and resources for teaching electric fields. In contrast, Alejandro continued to use conservative strategies despite having a priori selected a specific route of content to follow in teaching electric fields. These strategies give him affective stability since they reduce the likelihood of unexpected occurrences in his classes, and thus he controls the appearance of negative emotions, although this is an obstacle to change in the curricular and methodological structure of his PCK.

In sum, we believe that changes in PCK depend not only on what teachers think and do in their classrooms, but also on the kind of emotions they experience. The system of categorization of the emotions that we have established is a starting point for their integration with PCK. For future research however, it will be necessary to develop new instruments with which to characterize the affective domain as part of PCK (Sutton and Wheatley, 2003), and to determine its influence on changing the components of PCK. It will also be necessary to look more deeply into the emotions that activate behaviour and those that block it, since Darwin (1872) himself remarked on the existence of both stimulant and depressant emotions.

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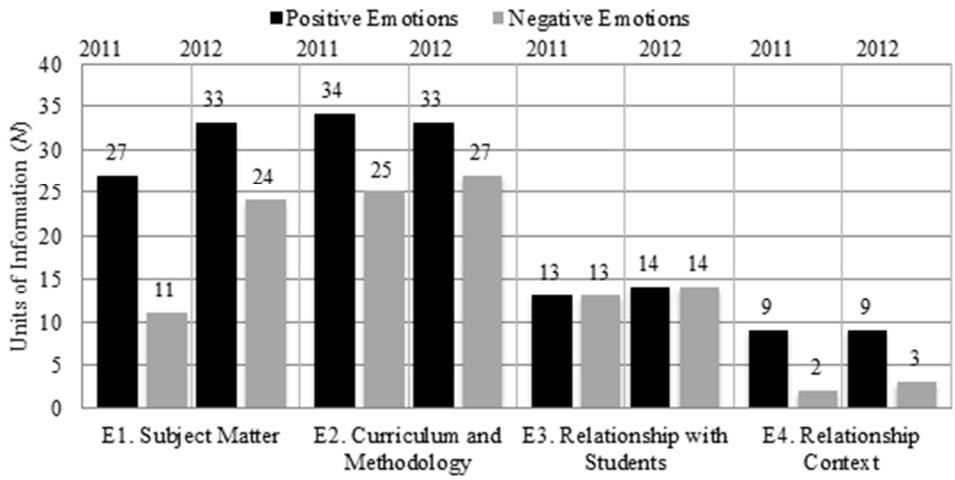

Figure 1. Causes of the emotions declared by Isabel.
150x79mm (96 x 96 DPI)

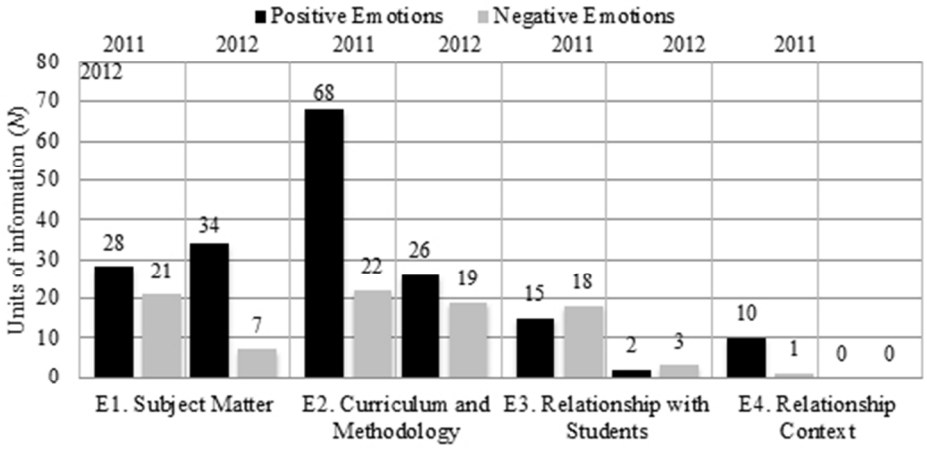

Figure 2. Causes of the emotions declared by Alejandro.
150x79mm (96 x 96 DPI)

Appendix: Categories of analysis for the PCK.

		Traditional tendency	Intermediate tendency	Constructivist tendency
A. Knowledge of the curriculum	A1. The content and its selection criteria	The central themes are more or less interesting for the teacher. They range from simple to complex.	The content as didactic transformation. The selection of content is given by successful experiences.	The content as integration and didactic transformation. The pupils' attitude is taken into account.
	A2. Organization of the content	Updated and simplified version of scientific knowledge.	There is a relationship with other subjects and contexts, but maintaining a rigid schedule.	Integrating the academic with the contextual.
	A3. Sources and resources	The sources used complement the information in the textbook. The resources are passive tools.	Varied resources and sources which facilitate the implementation, verification, and development of explanations.	Integration of different sources. Flexible and dynamic resources, adapted according to the context.
	A4. Objectives	Conceptual and procedural, aimed at solving and predicting a situation created using algorithms and definitions.	Conceptual and procedural, aimed at enhancing the qualitative observations, and the detection of regularities.	The goals extend to procedures and attitudes; they are achievable and are consistent with the content, the activities, and the proposed assessment.
B. Pupils' knowledge when learning the electric field	B1. Nature of the pupils' ideas	Pupils do not have relevant ideas at the start a new topic, or those ideas are regarded as errors that should be replaced; stopping to detect them is a waste of time.	We must recognize the ideas or previous knowledge of the pupil, because they are a source of motivation.	The exchange of ideas involves a progressive reworking of one's own ideas when interacting with the new school information in different contexts.
	B2. Learning difficulties	They are due to the characteristics of the pupils and conditions beyond the classroom.	They predict the difficulties but are not used during the planning.	They identify with the proposals in the literature on teaching content and are used in planning.
	B3. Motivation and participation	Motivation and participation are crucial factors in school learning. It is assumed however that they depend entirely on the pupil.	Active participation is understood as letting the pupils take part during the teacher's discourse. The motivation is a function of the utility of what they learn.	Active participation is understood as ceding control of the class to the pupils, and including them in decision-making in class.
C. Knowledge about evaluation	C1. Object and purpose of evaluation	Measure the minimum knowledge acquired by the pupil. One evaluates what is taught.	Corroborate the degree of achievement of the proposed objectives. The evolution of the pupils' ideas is evaluated.	Serve as a tool for self-regulation in the learning process and encourage learning to learn. One evaluates the teaching and learning process.
	C2. Who participates in the evaluation	Specifically it is the teacher who carries out the evaluations.	Peer evaluation is only used when there is time and for institutional requirements	Self-evaluation or peer evaluation is from the initiative of the teacher and the pupils.
	C3. Type of evaluation and instruments	Objective, sanctioning, and informative. Usually an individually written test which matches the questions and answers defined during class.	Summative assessment of the overall process. Multifaceted instrument, at least one test of an individual character and another of a group character.	Formative, continuous, and integral, with a metacognitive character. The pupil participates in his or her own evaluation.
	C4. Grading	Grading has a comparative and discriminant function. Evaluation is sometimes assumed as synonymous with grading.	Grading is presented as a provisional indication accompanied by proposals of action for improvements.	Grading just means the recognition of achievements pursued. It includes plans for improvements, and, according to the process followed, may be modifiable.
D. Knowledge about teaching strategies	D1. Strategy selection criteria	They are external to the pupil's context, leading to the teaching sequence being regarded as a rigid element.	Links elements of a reflective teaching at some points of the class.	Flexible criteria from the planning, fully consistent with the objectives of the class and the pupil's context.
	D2. Type of strategies and activities	They help to better assimilate the content, primarily aimed at mobilizing and corroborating the information.	They are varied; if time is short, the practical activities would be sacrificed.	They are varied; some promote autonomy when facing learning.
	D3. Teaching sequence	Inform - Check/Verify - Practice.	Exploring/introducing the concept - Explanation - Application of the content.	Motivate - Explore – Explain - Develop - Evaluate