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Exploring the emotions in Pedagogical Content Knowledge about the electric field

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ABSTRACT

The objective of this study was to characterise 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), the emotions and their relationship with PCK. The research was conducted during two consecutive years, before and after their participation in a project 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 pupil-centred or innovative tendency (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.

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Introduction

Following the model of Magnusson, Krajcik, and Borko (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; Mellado et al., 2014).

The objective of our study was to characterise the changes in the PCK of two Colombian physics teachers (Isabel and Alejandro) at the high school level (pupils of ages 17–19),

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the emotions and their relationship with PCK. The study was conducted over two consecutive years, before and after their participation in a project 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 project 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 & Kim, 2016; Nilsson, 2008).

Alonzo and Kim (2016) and Shulman (2015) note how classroom practice has been forgotten in many PCK studies. Alonzo and Kim (2016) 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 (Mellado, 1998).

In our case, and in accordance with what was stated by Alonzo and Kim (2016), we consider that PCK can be characterised 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, Berry, and Meirink (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 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 & Lasky, 2005) because teaching ultimately involves interaction with others, and hence emotions. In a recent review, however, Uitto, Jokikokko, and Estola (2015) note the paucity of research in the last 30 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; Mellado et al., 2014; Sutton & 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, Ritchie, Tobin, Sandhu, & Sandhu, 2013; Dávila, Borrachero, Cañada, Martínez, & Sánchez, 2015; King, Ritchie, Sandhu, & Henderson, 2015; Maria, Dos Santos, & Mortimer, 2003; Ritchie, Tobin, Hudson, Roth, & Mergard, 2011; Schutz & Zembylas, 2011; Vázquez & 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 & Vermunt, 2001) and how to be more effective as teachers in handling the discipline itself and in the relationship with their pupils (Sutton, Knight, & Mudrey-Camino, 2009). These same authors, however, observe how difficult teachers find it to regulate and manage their own emotions. Brígido, Couso, Gutiérrez, and Mellado (2013) and Borrachero, Brígido, Mellado, Costillo, and Mellado (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, Bozkurt, and Coskun (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; Shulman, 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 & 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 recognise 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; Mellado et al., 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, mobilising 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.

Overview of the study

This study focuses on the characterisation of the PCK about teaching the electric field, the emotions and their relationship with PCK during two consecutive academic years (2010/2011 and 2011/2012). Consequently, the objectives are:

(1) To describe the PCK of two physics teachers during two consecutive courses before and after their participation in an innovation project on teaching the electric field.
(2) To characterise the emotions and their relationship with PCK showed by two physics teachers, before and after their participation in an innovation project on teaching the electric field.

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 (Melo-Niño, Cañada, & Mellado, 2017). When we began the study, Isabel was 28 years old, was working in a private girls' school, and had 5 years of teaching experience in secondary education and 2 years in high school. Alejandro was 30 years old, and had 7 years' experience teaching physics in high school and 1 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 and were taught in classes of from 15 to 30 pupils.

The researchers are teacher education instructors. Their role during the PCK characterisation phase was that of observers, not participants.

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, Mulhall, and Berry (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 (Melo-Niño et al., 2017). 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

The content representation matrix (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 systematisation and analysis of the data were conducted following the techniques of content analysis, including the following steps: (a) identification of units of information from each instrument or tool used to acquire data; (b) coding the units of information; (c) categorising the units of information; (d) analysis of the units of information; and (e) incorporating into the description the categories emerging from the analyses. The entire process was carried out with the support of 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 2010–2011 and 2011–2012 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 three tendencies: the traditional tendency or teacher-centred practice (TT), its opposite, the innovative tendency or pupil-centred practice (TC), and an intermediate tendency (TI) which includes categories that might be somewhat closer either to the teacher- or to the pupil-centred practices. In accordance with the hypothesis of progression of Porlán and Rivero (1998), evolution from the traditional to the innovative tendency is considered a progression, and the contrary a regression. For the USA's National Research Council (1996) too, pupil-centred orientations are an indicator that teaching strategies of inquiry and innovation are being implemented in classrooms.

In carrying out this classification, we considered the descriptions given by the models of teaching in the didactics of experimental sciences (Domingos-Grilo, Reis-Grilo, Ruiz, & Mellado, 2012; Schneider & Plasman, 2011; among others) and their overlap with the data that were collected. All the descriptions therefore refer to content concerning electric fields. The results were presented together to three expert researchers to confirm the relevance and reliability of the description. The final codebook is summarised 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 characterising 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.

Results

Table 2 summarises the dominant tendencies of Isabel's and Alejandro's PCK during 2010–2011 and 2011–2012. In each category, we identified the dominant tendency from

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

	E1. Content	E2. Curriculum and methods	E3. Relationship with the pupils	E4. Relationship with the context
Description	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.
Indicators	• Level of understanding of the electric field during undergraduate education. • The epistemological reconstruction of the model of the electric field that each teacher makes in order to teach it.	• The use of demonstrations related to lines of force and electrification. • The results of evaluations of the vector representation of the electric force.	• The pupils' construction of explanations of the relationship between force and electric field. • The pupils' assessments of the teaching strategies used in explaining electrification.	• Their colleagues' opinion of their teaching methods. • The school's support and endorsement of the teacher's work.

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 innovative – TC), or with only minor variations of up to 5%.

In the table, the categories in which a progression occurs are shaded in light grey: 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.

Table 2. Predominant tendencies of the PCK.

		Isabel		Alejandro	
PCK components	Categories	2010–2011	2011–2012	2010–2011	2011–2012
A. Knowledge of the curriculum concerning electric fields	A1. Content and selection criteria	TT	O	TI	TI
	A2. Organisation 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

Notes: TT, traditional tendency; TI, intermediate tendency; TC, innovative tendency; O, the three tendencies emerge equally.

The categories in which a regression occurs are shaded in dark grey: a change from a mixture in tendencies or an intermediate tendency to a traditional one and from an innovative tendency to a traditional one. We take a teacher to have developed their PCK when the changes in the different categories describing it are in the direction of the innovative trend and persist over time.

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 2010–2011 academic year was characterised by starting from a simpler theme (electric charge) to a more complex one (electric fields). During the 2011–2012 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 organisation 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 recognised 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 on electric field teaching

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 2010–2011, a total of 134 units of information were classified, and in 2011–2012 a total of 152.

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.

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

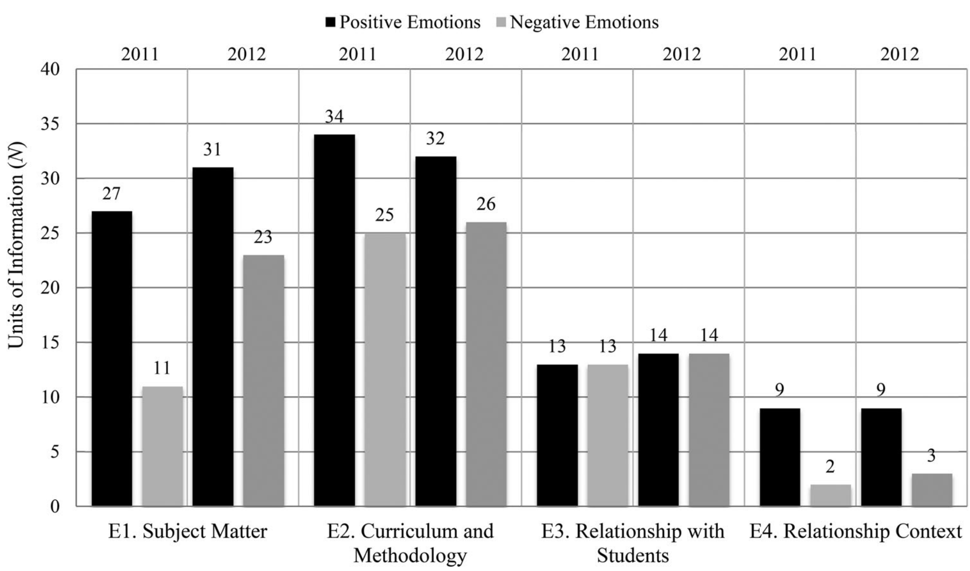

Figure 1. Causes of the emotions declared by Isabel.

made during the innovation project 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 organisation 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)

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.

Despite the apparent increase in negative emotions towards the content she is teaching that we observed in 2012 (see Figure 1), a chi-squared test and applied to evaluate the progression/regression of the total amount of positive/negative emotions during the two years of the study gave a p-value (.357) greater than the significance level (.05), so that the differences are not significant.

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 2010–2011 and 91 in 2011–

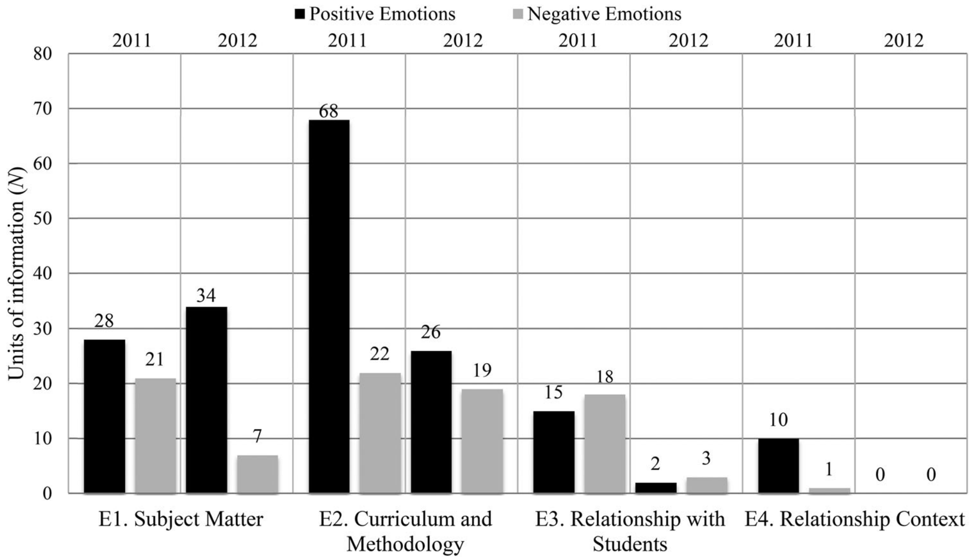

Figure 2. Causes of the emotions declared by Alejandro.

2012. 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.

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 organisation of the physics laboratory, because the pupils were always organised 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)

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

Despite the variations in the quantity of positive and negative emotions, especially those relating to the content, curriculum, and methods as is shown in Figure 2, on applying a chi-squared test to evaluate the progression/regression of the total amount of positive/negative emotions during the two years of the study, we found a p-value (.739) that was greater than the significance level (.05). The differences are therefore not significant.

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 summarised 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. To evaluate the progression/regression of the amount of positive/negative emotions during the two years of the study for each content, we used chi-square test or Fisher's exact test with the support of the SPSS-14 software package.

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 charge. 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

Table 3. The declared emotions about teaching specific content.

	Isabel					Alejandro				
	2011 ($N = 134$)		2012 ($N = 152$)			2011 ($N = 183$)		2012 ($N = 91$)		
Content and its teaching	Positive emotions %(*n*)	Negative emotions %(*n*)	Positive emotions %(*n*)	Negative emotions %(*n*)	Sig.	Positive emotions %(*n*)	Negative emotions %(*n*)	Positive emotions %(*n*)	Negative emotions %(*n*)	Sig.
1. Electrification of matter	9.0% (12)	6.0% (8)	7.3% (11)	6.6% (10)	ns[a]	12.0% (22)	3.3% (6)	12.1% (11)	–	ns[b]
2. Definition of electric charge	4.5% (6)	–	8.6% (13)	3.9% (6)	ns[b]	14.8% (27)	–	12.1% (11)	–	†
3. Definition of electric force – Coulomb's law	6.0% (8)	–	3.9% (6)	–	†	–	5.5% (10)	8.8% (8)	–	** [b]
4. Superposition of electric forces	9.0% (12)	14.2% (19)	5.9% (9)	3.9% (6)	ns[a]	5.5% (10)	4.4% (8)	9.9% (9)	6.6% (6)	ns[a]
5. Definition of electric field	4.5% (6)	6.0% (8)	5.9% (9)	5.3% (8)	ns[a]	7.1% (13)	6.6% (12)	11.0% (10)	6.6% (6)	ns[a]
6. Superposition of electric fields	4.5% (6)	6.0% (8)	5.9% (9)	3.9% (6)	ns[a]	–	5.5% (10)	7.7% (7)	5.5% (5)	* [b]
7. Electric field lines	11.2% (15)	–	12.5% (19)	5.3% (8)	* [b]	12.0% (22)	–	–	6.6% (6)	** [b]
8. Difference between field and electric force	4.5% (6)	6.0% (8)	6.6% (10)	5.3% (8)	ns[a]	–	5.5% (10)	–	6.6% (6)	†
9. Relationship between electrostatics and electrokinetics	9.0% (12)	–	–	9.2% (14)	** [b]	14.8% (27)	3.3% (6)	6.6% (6)	–	ns[b]
Total	61.9% (83)	38.1% (51)	56.6% (86)	43.4% (66)	ns[a]	66.1% (121)	33.9% (62)	68.1% (62)	31.9% (29)	ns[a]

Note: Differences significant at *$p < .05$; **$p < .001$; ns: differences not significant;
[a]Chi-square test;
[b]Fisher's exact test;
†The necessary conditions for the application of the Chi-square test or Fisher's exact test are not fulfilled.

aroused the most negative emotions. This situation changed drastically in the second year for the content related to definition of charge and electric field lines, for which she said she had experienced both positive and negative emotions. However, application of a Fisher's exact test confirmed that there was only a progression in both positive and negative emotions from one year to the next in the content related to electric field lines.

Unlike the first year, the relationship between electrostatics and electrokinetics only generated negative emotions for her since, during the innovation project; 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. There was, however, a significant regression in the number of positive emotions, a regression linked to the new relationship of causality that she proposes for the curriculum, in which electric force is the effect of the field.

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. Also, in three of the items of content analysed, there were significant differences in the amount of positive and negative emotions for the two years of the study, mainly due to his understanding of that 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. 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.

The subject where it cannot apply chi-square test or Fisher's exact test is definition of electric force in Isabel and definition of electric charge and difference between field and electric force in Alejandro. Those subjects are valued by teachers as very easy or difficult to teach.

Finally, the results presented in Table 3 indicate that, although in neither case was there a significant change in the total percentage of positive and negative emotions, there were indeed progressions and regressions, and that these depended on which content was being taught and were different for each teacher.

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, that they affected some components of PCK more than others, and that they have to be elicited.

The tendencies defined to characterise the PCK about the electric field – traditional, intermediate, and innovative – show that various trends coexist for each category of this PCK, and that it is sometimes difficult to define a single tendency for each teacher's overall PCK. The tendencies in the two cases we have analysed are due to the inherent difficulties of the content, such as the relationships that the teachers establish between force and electric field, and their knowledge of the curriculum.

We have also shown that the progression in each component of the PCK is not always in the same direction, whether from the traditional tendency to the innovative, or vice versa. The emergence of the mixed category between these tendencies (O) is a reflection of this fact. This new category represents a possible change in which the teacher selects aspects of both the traditional tendency and the intermediate or innovative tendency to organise their teaching of the content in question, rather than positioning themselves distinctly in another tendency. Isabel is a clear example. She went from a more teacher-centred PCK to an eclectic PCK that was a mix of tendencies, and showed a greater change in her PCK than Alejandro.

The progression or regression in each component of the PCK depended on the starting tendency. This was the case with Alejandro. His 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, both of which were teacher-centred.

With respect to our second objective, 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 role of the emotions as amplifiers and filters of choices and actions is an important, but little explored element in current models of science teachers' professional knowledge (Gess-Newsome, 2015). The present study may provide some signposts for such exploration.

Jameau and Boilevin (2015) showed that the events occurring during teaching result in new professional knowledge through two regulation loops – a short one during the lesson, and a long one on the scale of year-to-year. The case of Isabel, for instance, shows that, in her classes during the first year, she opted for traditional teaching practices with respect to her pupils' behaviour due to the negative emotions she experienced. She acquired new professional knowledge from one year to the other thanks to the combination of positive and negative emotions towards the curriculum, methods, and content catalysing 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 & 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 recognising that something can be done better than it is being done at present. Elliot (1991), 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. In the PCK model, emotions acquire an amplifier or filter role that conditions teachers' actions and choices (Grangeat & Hudson, 2015; Kind, 2015).

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.

Finally, the system of categorisation of the emotions that we have established is a starting point for their integration with PCK. Nevertheless, its relationship with the topic-specific and domain-specific needs to continue to be explored. For future research, it will be necessary to develop new instruments with which to characterise the affective domain as part of PCK (Sutton & Wheatley, 2003) and to determine its influence on changing the components of PCK, so that those instruments can be integrated into the programmes of teacher development.

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Appendix. Categories of analysis for the PCK.

		Traditional tendency (TT)	Intermediate tendency (TI)	Innovative tendency (TC)
A. Knowledge of the curriculum	A1. The content and its selection criteria	Simplified version of the scientific content. 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. Organisation 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.	Sometimes use of resources and sources for 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 recognise the ideas or previous knowledge of the pupil, because they are a source of motivation. However we do not considered explanatory diagrams of students.	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	Objective, sanctioning, and informative.	Summative assessment of the overall process.	Formative, continuous, and integral, with a

(*Continued*)

Continued.

		Traditional tendency (TT)	Intermediate tendency (TI)	Innovative tendency (TC)
	and instruments	Usually an individually written test which matches the questions and answers defined during class.	Multifaceted instrument, at least one test of an individual character and another of a group character.	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 mobilising 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