International Journal of Science Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tsed20

Emotional performance on physics and chemistry learning: the case of Spanish K-9 and K-10 students

M.A. Dávila-Acedo , F. Cañada , J. Sánchez-Martín , D. Airado-Rodríguez & V. Mellado

To cite this article: M.A. Dávila-Acedo , F. Cañada , J. Sánchez-Martín , D. Airado-Rodríguez & V. Mellado (2021): Emotional performance on physics and chemistry learning: the case of Spanish K-9 and K-10 students, International Journal of Science Education, DOI: 10.1080/09500693.2021.1889069

To link to this article: https://doi.org/10.1080/09500693.2021.1889069

Published online: 21 Feb 2021.

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION
https://doi.org/10.1080/09500693.2021.1889069

Emotional performance on physics and chemistry learning: the case of Spanish K-9 and K-10 students

M.A. Dávila-Acedo[a], F. Cañada [a], J. Sánchez-Martín[a], D. Airado-Rodríguez [b] and V. Mellado[a]

[a]Departamento de Didáctica de las Ciencias Experimentales y las Matemáticas, Universidad de Extremadura,, Badajoz, Spain; [b]Departamento de Didáctica de las Ciencias, Universidad de Jaén,, Jaén, Spain

ABSTRACT

We studied the emotions experienced by students during the last two years of compulsory secondary education (15 and 16 years old) when learning physics and chemistry. The objective of this piece of research was to establish different relationship between emotions felt by students and variables like the didactic methodology or the kind of science they are learning. We have collected data from different subject blocks such as those related to matter, energy and electricity or kinematics and dynamics, and they were processed and analysed in order to establish relationships by courses. The sample comprised 282 students. The results revealed that pupils mainly experience more positive emotions towards the content of chemistry than towards that of physics. There is also a decrease in the mean frequency of positive emotions such as joy as they pass from K-9 to K-10, and an increase in negative emotions such as boredom. The pupils who experienced positive emotions towards chemistry content related these to how the teacher taught the subject, rather than to the content itself. Negative emotions towards physics contents were linked to the exclusive use of the textbook, solving physics problems, or giving oral presentations.

ARTICLE HISTORY
Received 22 March 2020
Accepted 7 February 2021

KEYWORDS
Emotions; pupils; secondary education; physics and chemistry; content; course; teacher

Science teaching and non-cognitive aspects

Is science only a matter of thinking? Traditionally, science education has been understood as a simple knowledge acquisition where affects and emotions[1] (and actually anything different from concepts) had no place (LeDoux, 2000; Pekrun, 1992). But it is a fact that teaching and learning activities are strongly charged with beliefs, attitudes and emotions stimulated and directed towards people, but also towards values and ideals, as old (Posner et al., 2005) and recent pieces of research point out (King et al., 2015; Mellado et al., 2014). In spite of these findings, traditionally and even nowadays, science is mainly represented in schools as an area of the rational, analytical curriculum, with hardly any relation to emotions (Garritz, 2010).

For years, social, cultural and emotional factors have been systematically excluded, being labelled by the dominant positivist orientations as improper or unscientific since

CONTACT J. Sánchez-Martín jsanmar@unex.es Departamento de Didáctica de las Ciencias Experimentales y las Matemáticas, Universidad de Extremadura, 06006 Badajoz, Spain

they were identified as something contrary to the objectivity of science (Bellocchi et al., 2013; Schutz & Zembylas, 2009). As stated above, the transmission of science as a set of finished and indisputable truths has removed science from the pupils' concerns and from the emotion that historically marked the moments of the construction of knowledge (Mellado et al., 2014). Science in itself is dynamic, open and it is in continuous reconstruction and like that should be transmitted to students (Van Uum et al., 2016). It is therefore more than obvious that *conceptual change is emotional as well as cognitive* (Thagard, 2008) and one must focus not only in cognitive aspects, but also in affective ones if a significant learning, in terms of science education, is pursued.

What are we talking about when we talk about emotions?

We refer to emotions as reactions to the information we receive in our relationships with the environment. The intensity of the reaction depends on the subjective assessment made of how this information will affect our well-being. These subjective assessments will involve prior knowledge, beliefs, personal objectives, perception of a challenging environment, etc. An emotion depends on what is important to us, as Bisquerra (2000) already stated out. It is more than obvious different types of emotions arise in different circumstances. The criteria for classifying them were not always a standard one, but several taxonomies can be applied attending to different aspects. Focusing on their effects upon behaviour, emotions can be classified into two types: positive and negative (Borrachero et al., 2019). Positive emotions produce pleasant feelings, with short temporal duration, and negative emotions produce unpleasant feelings and the mobilisation of many resources to face them. Other authors have proposed more complex models based on the interaction between the intensity of emotions or the level of activation of the individual (excitation/relaxation) and the assessment of the situation which involves these emotions (pleasant/unpleasant) (Tyng et al., 2017).

The roots of the emotional implications in science education

Starting from constructivism, which has been the main theoretical framework for science education during the last decades, emotions have been increasingly gaining interest inside the educators and researchers: teachers who ignore the affective dimension of learning might be limiting conceptual change in their pupils (Chiang & Liu, 2014; Duit & Treagust, 2012). The first references about the importance of emotions in education can be found in authors like Damasio (1996). Afterwards, other specialist kept on researching and applying those recent discoveries to science education (Tobin, 2010).

In this line, the importance of emotions in science learning is well established in the literature with authors like Tobin (2012) and Tomas and Ritchie (2012) who proposed that emotions are a central part of the action of learning science, and function as a social 'glue' that interconnects individual and collective interests and actions.

In terms of academic research, the interest in linking science education and emotions is more than evident if one looks at the numerous studies which have noted that both cognitive and affective aspects influence the teaching and learning process (Mellado et al., 2014)

Learning science is much more than a cognitive process because, in order to learn, it is necessary to be able to do (skills, knowledge and capabilities) and to want to do (disposition, intention and motivation) (Bathgate & Schunn, 2017). It has been already described elsewhere (Bellocchi et al., 2013) that academic knowledge is learnt better when the pupils have emotional events that support the cognitive aspects of scientific contents. Other authors have recently pointed out this specifically regarding science education (Sánchez-Martín, Álvarez-Gragera, Dávila-Acedo, & Mellado, 2017; Kelly et al., 2012; Wickman, 2017).

Starting from the initial line of attitudes, the study of emotions in science teaching and learning opens up as a relevant line of research, and studies focused on this topic are becoming more and more frequent (Bellocchi et al., 2017; Kahveci & Orgill, 2015; King et al., 2015; Sanchez-Martin et al., 2017). Nonetheless, as pointed out previously (Tomas & Ritchie, 2012), the number of studies focused on the role of emotions in the learning of specific science content is scarce yet. It is, therefore, essential to continue in this line and identify the influence of emotions in the learning of the different contents in the science curriculum.

Secondary education: a turning point in the science learning process

Obviously, science education begins at the very early moment of formal instruction (usually, at 3 years old), although children face Science from their first steps. But perhaps one of the most influent period is the Secondary education (K7–K10). Many authors (Cañada, Sánchez-Martín, & Dávila-Acedo, 2020) have already pointed out the need for diagnoses of the emotions that arise in the students at classrooms during this Secondary Education stage because it will, therefore, provide a basis for intervention in the improvement of science learning, emphasising those activities that promote more positive emotions (King et al., 2015). Additionally, it is an already known fact that negative emotions limit the ability to learn (Pekrun & Linnenbrink-Garcia, 2014) and consequently, positive ones should promote learning within this period. However, the real role of emotions in learning process is still far from being completely understood (Sinatra et al., 2014). For example, Lavega et al. (2014) already identified an ambiguous value for relevant emotions such as surprise, which can be positive or negative. Is a negative surprise an obstacle for students' learning? Maybe yes, but it is also possible that negative surprise (as well as fear, reject or anxiety) could impact in the motivation dynamic for forcing the student to overcome a difficult (Mellado et al., 2014). Perhaps, this has to be with the classical theory of Vigotsky's Zone of Proximal Development or more recently, with the flow theory (Sánchez–Martín et al., 2017) in gamification and game designing.

If one tries to understand which is the real evolution of the emotional performance in science learning along the instruction process, primary education appears as a period where pupils (K1–K6) usually have positive emotions and attitudes towards science (Mellado et al., 2014). This decreases with age, especially during the final years of secondary education (K9 and K10) (Beauchamp & Parkinson, 2008). Along secondary education (K7–K10), it has been previously stated by our research group that the emotions depend on the content being taught (Sánchez–Martín et al., 2017). Something occurs during this stage that make it a real and significant turning point in how students react to the science learning process, so the importance of focusing it in the educative research.

Secondary education (K7–K10) pupils' positive emotions towards particular science content are related to self-efficacy, or the belief in their own ability and competence to learn that content. Self-efficacy is closely related to self-regulation, and it is a powerful variable in being able to predict pupils' achievement (Cakiroglu et al., 2012).

Emotional depression towards sciences is attributed to the fact that, as time goes by, secondary education pupils (K7–K10) create an image of school science as being boring, difficult, overly theoretical and of little use. Other causes that might have an influence are the teacher, the lack of practical work or the excessive orientation in the classes to preparing for examinations (Robles et al., 2015).

Up to university students: the gap still appears in pre-service primary teachers

But some researchers went further. Borrachero et al. (2014) analysed the recall that 510 first-year undergraduates of 15 different degree courses had of their emotions towards the sciences in secondary education. They reached the conclusion that when the students felt they were able to learn some certain content, they showed an increase in their positive emotions towards that content. But when they did not feel capable of learning the content, they more often experienced negative emotions. This is especially important in physics and chemistry for which more negative emotions are recorded and self-efficacy has the most influence (Brígido et al., 2013).

Focusing on physics content, which is that which generates the strongest negative emotions, Borrachero et al. (2013) concluded that there are notable differences between prospective primary and secondary education teachers in the attribution of causes to the recall of emotions in secondary education. For pre-service primary education teachers, the causes of positive emotions are mostly attributed to their teachers than to the subject's content or to themselves as pupils at school. However, they mainly attribute the causes of the negative emotions to themselves when they were pupils and to the physics content. Pre-service secondary education teachers specialising in science and mathematics attribute the causes of their negative emotions towards Physics mainly to their school teachers and the content, and the causes of positive emotions to themselves as pupils and to the problem-solving and laboratory activities.

There is still a long way to understand the real impact of emotional aspects in the science learning process and how to implement more and better educative strategies for enhancing the experience for students, especially those in Secondary Education.

The research problem

As can be easily checked out (see above), many researchers are currently working on the subject emotional and affective domain and its relationship with the learning experience. However, the more we discover about this task, the more we realise we are long for understanding how both concepts are linked and subsequently, how to influence the emotional sphere in order to enhance the learning process in science education.

Understanding the hidden links between emotion and learning science is the real research problem's key.

In this sense, we agree with Wan and Lee (2017): more studies are needed which analyse the causal relationships between the cognitive and the affective in secondary education pupils when they are learning science.

Following this line, the present research aims to achieve the following objectives:

1. To analyse the emotions of pupils of the third (K-9) and fourth (K-10) years of Compulsory Secondary Education (ESO in Spanish Educational System) towards the physics and chemistry content selected from the syllabus.
2. To analyse and determine whether there are significant differences between course years in the emotions experienced by secondary education pupils when learning physics and chemistry.
3. To determine and analyse the relationship that exists between various aspects related to teacher and pupil as being the causes of positive or negative emotions towards learning physics and chemistry content.

Research methods

Sample

According to Box et al. (2005), the process carried out to select the surveyed pupils was cluster sampling. This provided a representative sample of students of Secondary Education within the region were we are working on. The sample size was calculated for a 95% confidence interval, a variance $p = .5$ for the least favourable situation and 5% margin error. In summary, the sample consisted of 282 pupils from six schools in Badajoz (Spain) distributed over the two studied courses: third (14–15 years old, K-9), and fourth of Compulsory Secondary Education (15–16 years old, K-10). One hundred and fifty-two (53.9%) belonged to the first category, whereas 130 (46.1%) belonged to K-10. By gender, 46.5% of the sample were girls and 53.5% were boys.

Ethical disclosure statement

Regarding ethical procedures, all participants provided informed consent when filling up the surveys and gave us consent to use their answers for our research with academic purposes. Obviously, anonymity was ensured by avoiding identification of questionnaires.

Instrument

A quantitative non-experimental or 'ex post facto' methodological approach was taken to perform this research. The data acquisition instrument was a questionnaire of the authors' own elaboration, based on the questionnaire of Borrachero et al. (2013) asking for opinions on emotions towards Physics and Chemistry. The use of this kind of instrument is widely accepted by other researchers, and can be found in different works (De Vaus, 2013).

The questionnaire is structured as follows:

- Title of the questionnaire specifying whom it is addressed to.
- Introduction where the objective of the questionnaire is given, highlighting its anonymous nature.
- List of personal variables in order to obtain information about the sample.
- Table with 14 emotions, 7 of which are positive and 7 negative, scored on an 11-point Thurstone scale (Rahayu, 2015).
- Questions about the scientific content imparted in physics and chemistry. A total of five blocks of content, divided in turn into sub-contents.
- Different questions about the physics and chemistry teacher's evaluation, attitude and methods.

Previous works (Sánchez–Martín et al., 2017; Cañada et al., 2020) found the relevance of asking about emotions in terms of Likert or similar questionnaire in this 1–10 levels, so the individual can choose in a wider range that probably will lead the researcher to a more accurate description of the phenomena. However, this is discouraged if we deal with a low number of individuals, which is not the current case.

In order to determine the emotions experienced by pupils when learning physics and chemistry, a classification of the emotions was made into positive and negative based on the categorisations reported elsewhere (Bisquerra Alzina & Pérez Escoda, 2007), although more implications were taken into account (Damasio, 2012; Goleman, 1995). This classification does not imply moral or ethical aspects, it is only a way of categorising them according to the pleasant/unpleasant feelings that arise in the individual when the emotion is felt. The survey does not reveal this categorisation to the students, so they are not able to classify each emotion in one or another category.

Table 1 lists the seven positive and seven negative emotions selected for this research to be scored on an 11-point Likert scale, with 0, 'Never' and 10, 'Maximum score'.

To verify the internal consistency of the questionnaire, its reliability was calculated using the covariation between the items of the different scales making it up. Table 2 presents the Cronbach reliability coefficients obtained for each scale of emotions, the positive and the negative. The values are all >0.80, so that it can be said that the reliability of the questionnaire is quite good.

Focused science content

The Secondary Education curriculum for Extremadura (Spain) was reviewed for identifying which science contents must be focused. Physics and chemistry content was selected in accordance with a specific law (SPAIN, 2007). Five blocks of content were established:

Table 1 Emotion taxonomy.

Classification of emotions			
Positive	Joy	Negative	Boredom
	Trust		Anxiety
	Fun		Disgust
	Enthusiasm		Fear
	Satisfaction		Nervousness
	Surprise		Worry
	Tranquillity		Sadness

Table 2 Reliability statistics of both positive and negative emotions towards learning physics and chemistry.

	3rd ESO		4th ESO	
	α	*N*	*α*	*N*
Positive emotions	0.823	7	0.832	7
Negative emotions	0.820	7	0.845	7

Matter (I); Energy and Electricity (II); Structure and Changes of Matter (III); Kinematics and Dynamics (IV); Work and Energy (V). Each block was then divided into sub-contents. In this part, the pupils were asked to rate the emotions they experienced for each of the content topics on a Likert-type scale, with '0=minimum score' and '10=maximum score'. Blocks I (Matter), II (Energy and Electricity) and III (Structure and Changes of Matter) were common to both courses studied. In contrast, blocks IV (Kinematics and Dynamics) and V (Work and Energy) belonged only to the fourth course (K-10).

Comparisons based on content and levels are made according to the following structure:

a) Firstly, blocks I–III were compared between K-9 and K-10 students, so differences can be established. These blocks are common to both levels.
b) Secondly, since blocks IV and V are specific to K-10, an evolution of emotions is studied from block I to V only within K-10 students.

Emotion reasons

Another aim of the current work is to determine the reasons for feeling the specific emotions, both positive and negative, experienced by the pupils in the study. The traditional and statistical way of understanding *causality* is given by the following definition:

> the relation between a cause and its effect or between regularly correlated events or phenomena.[2]

Although statistically it should require a hard work to unequivocally establish the relationship between cause and effect, the current piece of research has addressed the identification of different causes by asking directly the students about their particular visions of what were the origins of such emotions. A classification was made of possible causes, considering two categories, one related to the teachers and the other to the pupils. This classification was of the authors' own elaboration, based on previous studies (Sánchez–Martín et al., 2017). Specifically, Table 3 presents the categorisation of

Table 3 Categorisation of aspects related to the teacher as possible causes of emotions.

Teacher		
Methods	P1	Laboratory activities
	P2	Group work and activities outside the classroom
	P3	Exclusive use of the textbook
Evaluation	P4	Evaluation
Attitude	P5	Teacher motivation
	P6	Clarification and resolution of doubts
	P7	Use of ICTs

Table 4 Categorisation of aspects related to the pupil as possible causes of emotions.

Pupils		
Results	E1	Marks obtained
Motivation to learn	E2	Giving oral presentations in class
	E3	Relating the content to daily life
	E4	Participating in science-related debates
Capacity to learn	E5	Solving physics problems
	E6	Memorising the Physics and Chemistry content
	E7	Using diagrams to understand the content

various aspects related to the teacher. This classification takes into account the identified categories that have been attributed to the professional performance of the teacher. In this sense, three categories are established: methods, evaluation and attitude. Regarding methods, all the strategies the teacher uses in the classroom are included: if the teacher puts in practice modern active-learning methods (such as Flipped Classroom, gamification, Problem-Based Learning …), the way he/she develops the oral-based class (magistral lesson), if he/she dialogues with the students or just talk in a teacher-centred teaching, etc. Regarding evaluation, the emotional perception of the way the teacher values the student's effort is considered: fair/unfair recognition of the student's work, kind of exams, expected results, etc. Finally, attitude refers the way the teacher interacts with the audience, in the sense of using new communication methods (TICs), solving doubts in a polite and comfortable way or the perceived passion for teaching.

Since not only the teacher could be the main reason for pupil's emotions, Table 4 presents the categorisation of various aspects related to the pupils as possible causes of emotions, both positive and negative. As can be easily seen, Table 4 categorises the external reasons for feeling such emotions in three big groups. These reasons are not related to the teacher's performance, but to aspects directly related to the student's experience. The first group of reasons are those related to the results obtained (either in previous courses or expected for the current one). It is more than obvious the experience (in terms of marks performance) is a relevant factor for the emotional disposition. The second group consisted of those motivational aspects,[3] that is, the internal vision of the scientific learning process that has to do, for example, with the way one face to give oral explanation in public, the interest of the scientific content for daily life or how much does one like the debates and the dialogical learning. The third big group has to do with relevant milestones one can achieve in the learning process, that is, the capacity to acquire the knowledge. In this specific block of reasons are included the following ones: capacity for problem-solving, the specific scientific content acquisition (theory) or the way of using diagrams for learning.

In both cases, the pupils were asked to evaluate each of the items as causes of positive or negative emotions. Each item was scored on an 11-point Likert scale, with '0 = minimum score' and '10 = maximum score'.

Statistical procedure

A 30 min questionnaire was used for data collection. Data were subsequently processed with SPSS 22.0 and The Unscrambler for Windows.

The sample constitutes has a normal distribution, as SPSS confirmed by Levene's test prior to the application of statistical techniques. The *T*-Student test was used for checking statistically significant differences. To this end, the mean scores were compared with the distributions of the quantitative variable (emotions) in the two groups established according to the academic levels (K-9 and K-10). The distribution of the sample had previously been found to satisfy the assumptions of normality using the Kolmogorov–Smirnov test ($p > .050$). In the statistical analysis of the data, a 95% confidence level was worked with. This is a very used technique for analysing a data set under normality and homocedasticity principles.

A principal component analysis (PCA) was performed in order to establish possible correlations between the variables, in this case, content (of physics and chemistry) and causes (teacher/pupil related).

PCA is a technique used to reduce the dimensionality of a set of data. This analysis seeks to maximise the variance of a linear combination of the variables. It maps each instance of the given dataset present in a d-dimensional space to a k-dimensional subspace so that $k < d$. The set of k new dimensions generated are called the principal components (PC) and each principal component is directed towards a maximum variance excluding the variance already accounted for in all the preceding components. The first principal component is the linear combination with maximal variance. The second principal component is the linear combination with maximal variance in a direction orthogonal to the first principal component, etc. The first principal component also represents the line that minimises the total sum of squared perpendicular distances from the points to the line. The principal components can be represented as:

$$\mathrm{PC}_i = a_1X_1 + a_2X_2 + \ldots + a_dX_d \quad (1)$$

where PC_i is the principal component 'i'; X_j the original feature 'j'; a_j the numerical coefficient for X_j.

Some previous works already pointed out the feasibility of such method for emotional measures in the oral speech and spoken emotion recognition (Van Der Wal & Kowalczyk, 2013; Zhang & Zhao, 2013). Other authors enlarged the use of PCA for other psychological concerns, such as membership in the classroom (Gray, 2017) or the analysis of emotional measurements in individual regulation (Gondim et al., 2015). However, it is not a very used technique in social sciences.

Results and Ddscussion

Both descriptive and inferential analysis were performed in order to identify some interesting insights. As said before, a comparison was established based on age and blocks. In addition, an evolution of emotions is shaped since blocks IV and V are specific for K-10 and not for K-9, so it designs a still-photograph of how emotions become more or less positive along a short period of time (from K-9 to K-10 course). For comparing, emotions were classified into negative or positive ones. Table 5 shows the mean frequency of responses in a 0–10 Thurstone scale.

According to the section *Research methods*, emotions were classified into two categories: positive and negative ones, depending on the pleasant/unpleasant effect on the individual. This classification, as said before, does not refer an ethical, moral or aesthetic categorisation, but just a way of evaluating the effect of them on the feeling subject. Obviously, all of the emotions are needed for the correct psychological equilibrium.

Table 5 Results of emotion count (positive vs. negative ones). Starred bold data presented significant differences ($\alpha \leq 0.05$)

Block	Content	K-9		K-10	
		+	−	+	−
Matter	Atoms and molecules	6.02	3.15	5.74	3.62
	Liquids, solids and densities	5.76	3.45	5.55	3.85
	Separation of elements in a mixture	**6.32***	2.85	**5.8***	3.56
	States of matter	6.56	**2.52***	6.33	**3.09***
	Pure substances and mixtures	5.98	3.12	5.81	3.25
Energy and electricity	Energy and forms of energy	5.63	3.32	5.43	3.87
	Heat and temperature	5.53	3.29	5.43	3.81
	Changes in the state of matter	6.41	**2.59***	6.32	**3.23***
	Electricity and electrical circuits	5.31	3.77	5.2	4
	Light and sound	5.48	3.05	5.35	3.18
Structure and changes of matter	Periodic table and periodic properties of elements	**7.25***	2.7	**6.37***	3.17
	Chemical formulation and nomenclature	6.24	3.28	5.83	3.57
	Chemical reactions and stoichiometry	6.03	**2.72***	5.78	**3.72***
	Moles, Avogadro's number	5.31	3.73	5.09	4.06
	Gases laws	5.34	3.64	5.26	4
Kinematics and dynamics	Motions	N/A		3.77	6.02
	Space, velocity and acceleration			3.5	5.88
	Forces			3.41	5.93
	Principles of dynamics			2.92	6.52
	Fluid force and presure			3.29	5.81
Work and energy	Kinetic and potential energy			4.05	4.7
	Work and power			4.19	4.72
	Heat, effects on bodies			4.15	4.9

Data analysis

Comparison based on levels: K-9 vs. K-10, segregated by subject blocks

Table 5 shows the general comparison between students, levels and positive and negative emotions. At a first glance, the initial intuition is that positive emotions are more commonly felt than negative ones, either within K-9 and K-10 students. The mean difference between these positive and negative emotions is around 2.7 points in the case of K-9 and 2 in the case of K-10. This means the contents in blocks I–III are mainly perceived under good (positive) emotions in both levels (K-9 and K-10).

When compared between them, significant differences (p-value under .05) can be observed only in five cases, which are marked with bold and starred data. These are the following ones:

- The level of positive emotions is significantly different and higher for K-9 students when dealing with separation of elements in a mixture (block I) and the periodic table and periodic properties of elements (block III).
- The frequency count of feeling negative emotions is significantly higher for K-10 when studying the states of matter (block I), the changes in these states (block II) and the chemical reactions and stoichiometry (block III).

Out of these five cases, no statistically significant differences can be confirmed.

The evolution of emotions: blocks IV and V for K12 students

The slight tendency from K-9 to K-10 levels shows a decrease in the frequency count of positive emotions and a raise of negative ones. In the current paper, this is not a very relevant effect. Positive emotions decrease from 5.9 to 5.6 in terms of the mean frequency and negative emotions raise from 3.2 to 3.6. This is in agreement with Beauchamp and Parkinson (2008), when they pointed out that as instructional path goes ahead, the student's emotional performance towards science becomes lower and lower and the students feel more and more uncomfortable when dealing with science topics.

In fact, this tendency grows exponentially when the results from blocks IV and V are analysed. These blocks are specific for K-10 students. As can be shown in Table 5, the performance of positive emotions is clearly below the values of negative ones (in terms of mean frequency), clearer in the case of block IV than in block V.

The results of this study regarding the decrease in the mean frequency of positive emotions when learning Chemistry content in passing from K-9 to K-10 suggest that this may be due to the increased complexity of the content addressed in each theme, as well as the increasing difficulty of the associated problems. As said before, it is represented by a slight variation.

Nonetheless, the most worrying results are those obtained in the blocks related to physics content (blocks II, IV and V), especially in those which are only studied by K-10 students. In the last cases, the mean frequency count of the negative emotions is greater than that of the positive emotions. Unfortunately, the data found in the present study are not isolated since they are coherent with our own study (Sánchez–Martín et al., 2017) of another sample of secondary education pupils about their emotions towards learning physics and chemistry content, in which the pupils experienced more positive emotions towards the chemistry content. They experienced more negative emotions towards the physics content. The current data are also consistent with previous studies (Borrachero et al., 2013) which analysed the recall of the emotions experienced by prospective secondary education teachers when they themselves were pupils studying science at that same educational stage, with those emotions being more negative towards learning the physics scientific content.

Another previous study was carried out by King et al. (2015). They worked with ninth graders (13/14 years) and analysed diaries that collected the emotions the pupils experienced during chemistry classes, finding a lack of interest and negative emotions of frustration, fear and discomfort towards learning new content. Instead, there was a change in the emotions from frustration and sadness to joy and happiness when they understood the content worked on, in this case, the formulation of chemical compounds. This is also in agreement with our data in the current work.

Regarding some aspects of advanced chemistry, Cheung (2015) analysed the self-efficacy of secondary education pupils in Hong Kong when they were learning Chemistry content (the elements of the periodic table, the periodic properties, chemical reactions and stoichiometry). In the study, the pupils showed medium to high values of self-efficacy towards learning that content. In the current work, instead, the pupils showed a greater mean of positive emotions than of negative emotions about these same topics of the content. Brígido et al. (2013) found out a probable correlation between high self-efficacy and positive emotions towards physics and chemistry. This could be an initial point for the analysis of the sample of the current work.

Negative emotions towards physics content are worrying because, as noted by Laukenmann et al. (2003), success in learning physics is linked to the existence of positive emotions towards that learning such as joy and interest. Thus, pupils with strong self-efficacy beliefs towards learning will overcome the problems or obstacles they encounter, experiencing positive emotions. But pupils unsure of their abilities will experience negative emotions such as anxiety or nervousness, which will be a limitation to their learning (Schunk & Usher, 2011; Usher & Pajares, 2008).

Principal component analysis of the studied variables

Given the large size of the data set generated in the framework of this research, a technique of dimensionality reduction was applied in order to extract the maximum information possible from it because, when dealing with such large sets of data, there is the danger that some of the information might remain hidden. The technique used was PCA which has proven to be a very useful tool to extract information from large and complex tables of data. The part of the data set subjected to PCA was the one corresponding to measures of positive emotions towards physics and chemistry content, as well as towards the causes related to the teacher's evaluation, attitude and methods, and towards aspects related to the pupils, such as their ability to learn, motivation to learn and grades obtained. The results of a PCA are normally summarised in two types of plot – one of loadings and the other of scores. Figure 1 shows the loadings for the first and the second principal components (PC1 vs. PC2), which explain 76% and 6% of the total variance of the system, respectively. Those variables with a high loading on a particular principal component (PC) define the meaning of that PC. The loadings plot resulting from a PCA is particularly useful to detect correlations between variables. To determine the correlation between variables, one must bear in mind that when two variables have high loadings on the same PC, those variables are strongly correlated. If the loadings of the two variables have the same sign then the correlation is positive, and negative if they have different signs.

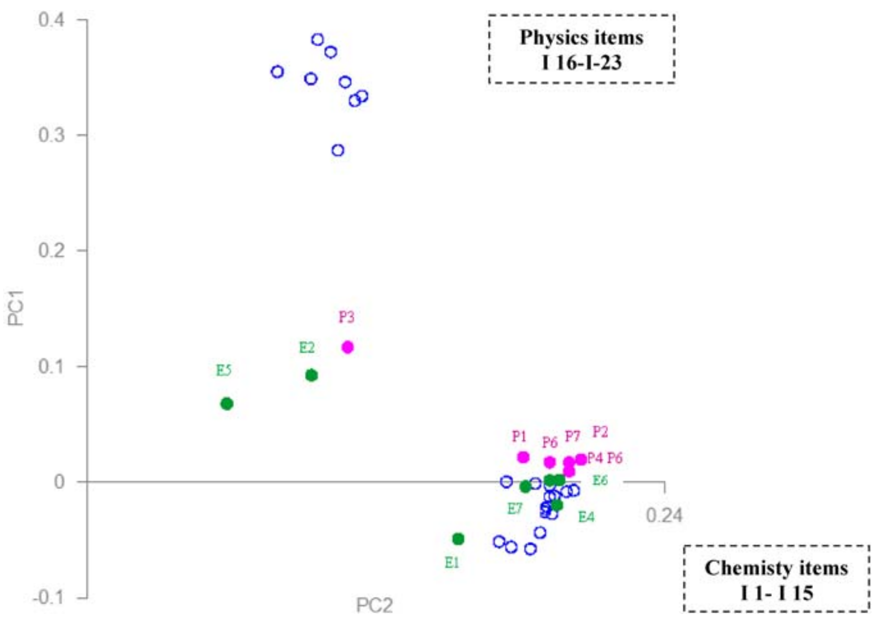

Figure 1 Loadings plot for the principal components 1 and 2.

The conclusions that one draws from the loadings plot of Figure 2 will be discussed in what follows. Considering only the distribution of the various items of the content on the loadings map, one can see that items 1–15 are grouped in the high part of the first principal component (PC1, horizontal axis), whereas items 16–23 are grouped in the high part of the second principal component (PC2, vertical axis). As items 1–15 are chemistry content, and items 16–23 physics content, the first conclusion reached, given their grouping, is that the two disciplines cause the pupils different quantities and types of positive emotions, which would contribute to the decoupling of the two disciplines with regard to the pupils' emotions. It can also be said that all the Physics items considered in the study were strongly correlated, with this correlation being positive as they were all grouped in the high part of PC2, and that all the chemistry items were also correlated positively with each other, being grouped in the high part of PC1. Thus, for instance, the pupils who show positive emotions towards the item 'Atoms and molecules' (I1) also show them to the items 'The periodic table and periodic properties of the elements' (I11), 'Formulation and nomenclature' (I12), and 'Chemical reactions and stoichiometry' (I13). Observing the two point clouds more closely, one can see that item 21 ('Energy. Forms of energy: kinetic energy and potential energy') is the one with the weakest correlation with the other physics items as it is the furthest from the point cloud which they form. Considering not only the items but also the distribution of the various causes studied related to the teacher (pink dots), one observes that all these causes except P3 ('Exclusive use of the textbook') are in the high part of PC1, very close to the point cloud formed by the chemistry items. This means that these causes of positive

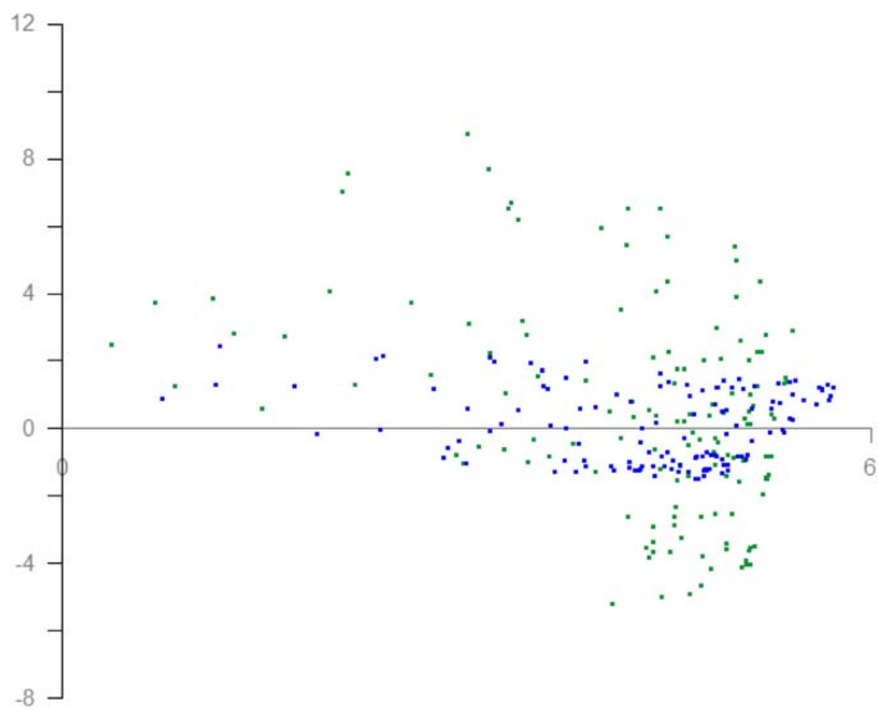

Figure 2 Score plot for the principal components 1 and 2.

emotions related to the teacher are correlated positively with the chemistry items. For example, a pupil showing positive emotions towards chemistry items will also show positive emotions towards aspects related to the teacher's methods, such as doing practical laboratory activities (P1), group work and activities outside the classroom (P2), as well as to aspects related to the teacher's attitude, such as clarification and resolution of doubts (P6), and the use of new technologies (ICTs) (P7). It is logical that pupils with positive emotions towards doing laboratory practicals or activities outside the classroom usually do not show such emotions towards the exclusive use of textbooks (P3).

Considering also the causes related to the pupils (green dots), one observes that all but two of the pupil-related aspects examined in this study lie within or very near the point cloud formed by the Chemistry content. The two exceptions are E2 ('Giving oral presentations in class') and E5 ('Solving physics problems'). It is logical that solving Physics problems correlates with neither the Chemistry content nor oral presentations since this is something that is worked on very little during this educational stage. Again, this means that all the causes related to pupils which have been considered in this study except E2 and E5 are positively correlated with the chemistry content as far as positive emotions are concerned. In view of these results, it can be affirmed that a pupil with positive emotions towards the chemistry content also shows them towards aspects related to motivation and the capacity to learn, such as relating the content to daily life (E3), using diagrams to understand the content (E7) and participating in science-related debates (E4). As shown in the plot, the correlation of E1 ('Marks obtained') with the Chemistry content is weaker than that of E3, E4, E6 and E7, probably because facing an evaluation creates uncertainty and fear in the pupils, regardless of the subject. Regarding the Physics items in this study, no clear correlations were observed with any of the aspects considered, whether related to the teacher or the pupils, insofar as positive emotions are concerned.

Figure 2 shows a score plot of the PCA (K-9, green dots; K-10, blue dots). The score of a sample on a particular PC describes the characteristics of that sample with regard to the variables with high loadings on that PC. Thus, samples with similar scores on the same PC can be said to be similar with respect to the variables that most contribute to that PC. The score plot is typically used to detect grouping, similarities and differences between samples.

One observes in Figure 2 that most of the samples are clustered along the high part of the horizontal axis (PC1), as were the chemistry topics and the causes related to the teacher and the pupils commented on above in the loadings plot. This means that most pupils expressed positive emotions towards the Chemistry content and towards the teacher- and pupil-related causes correlated with that content. But, finding the maximum density of points in this part of the plot, one can also state that most of the positive emotions expressed by the pupils were towards the content of chemistry, not physics, because the density of points at the high part of PC2 is very low.

There have been results indicating that emotions towards learning content are related to the strategies and activities undertaken in class. King et al. (2015) found that, when classes include stimulating activities and experiments about energy, the pupils' emotions were very positive: amazement, surprise, joy and happiness. In a study with secondary pupils on physics content, Afolabi and Akinbobola (2009) found that the use of methods which encourage the pupils' active participation, such as a problem-based learning technique, leads to a better understanding of physics concepts as well as increasing the pupils' confidence, especially for those who show low capacities for learning that content.

It is well known that the success attributed to internal causes (Wang & Hall, 2018) (the variables in Table 4 concerning pupils) led to greater self-esteem than the success attributed to external causes (the variables in Table 3 concerning the teacher); however, the failure attributed to internal causes led to lower self-esteem than the failure attributed to external causes. In this current research study, the pupils attributed their negative emotions towards physics content to the use of the textbook in class. In contrast, they attributed positive emotions to themselves when solving a physics problem or giving oral presentations. In the case of chemistry content, the pupils who experience positive emotions attribute them to aspects related to their ability and motivation to learn. The negative emotions, however, were attributed to the teacher's method and attitude.

Relationship between emotions and level of pupils

Figure 3 shows the mean score of the frequency of the positive emotions, depending on the course they are in. The mean frequencies of the positive emotions can be seen to be between 4.5 and 6.5, being greatest in the third year for satisfaction (6.37), joy (6.30) and confidence (6.14). The *T*-Student test was applied for identifying statistically significant differences (*p*-value under .05). Significance was only found in the case of positive emotions joy (0.003), fun (0.048) and tranquillity (0.041), being greater amongst K-9.

Regarding negative ones (Figure 4), the mean frequencies were found between 3 and 7. K-10 students showed higher levels for boredom (6.25), nervousness (6.02) and worry (6.71). This may be because more content related to Physics is taught in fourth grade, whereas more chemistry is taught in third grade. Statistically significant differences were only found in the case of boredom (0.002), disgust (0.004), fear (0.004) and sadness (0.004), so it can be said that these negative emotions experienced a significant raise from K-9 to K-10 sample.

In the present study, there was a decrease in the mean frequency of all the positive emotions when passing from the 3rd to the 4th year, and an increase in all the negative

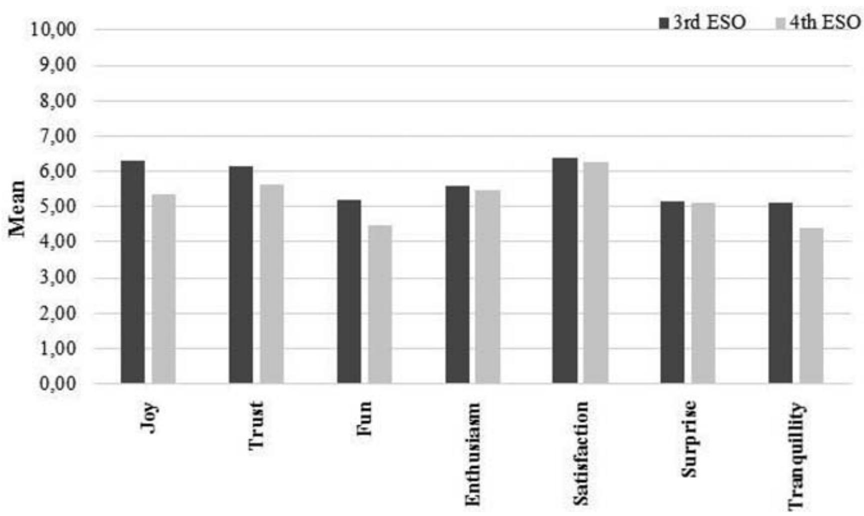

Figure 3 Mean frequency of positive emotions experienced by secondary pupils when learning physics and chemistry depending on the course.

emotions. These results can be compared to our own study (Davila-Acedo, Canada, Sánchez-Martín, & Mellado, 2016) with another sample about their emotions towards learning Physics and Chemistry. There was a decrease in the frequency of positive emotions (joy, confidence, happiness, tranquillity, surprise and excitement) and an increase in the negative emotions (worry, shame, disgust and anger) when passing from the third to the fourth year.

The decrease in the positive and increase in the negative emotions in secondary education in these subjects coincides with the decline of positive attitudes towards science which has been reflected in numerous and classical studies (Osborne et al., 2003). The combination of negative attitudes and emotions towards physics and chemistry content can influence the choice of subsequent career paths and university degrees that involve these subjects (Custódio et al., 2013) because emotions are fundamental in decision making (Angie et al., 2011). The fall seen in many countries in the numbers of students doing chemistry degrees, and even more so in the case of physics degrees, may be related to the emotionally difficult context surrounding science learning during their secondary education stage, in which they did not manage to enjoy learning these subjects.

Trigwell et al. (2012) noted that the strength of positive emotions such as hope and pride, and weakness of negative ones, are related to a deep approach to learning and high performance. Thus, students who are proud and satisfied with their academic achievements achieve more meaningful and deeper learning, managing to regulate and improve their emotions. However, students whose expectations were not realised experienced negative emotions such as anger, boredom or frustration during the learning process.

Nonetheless, King et al. (2015) noted that there are differences in emotions, and that one should not make the generalisation that, for learning, all positive emotions are good and all negative ones are bad.

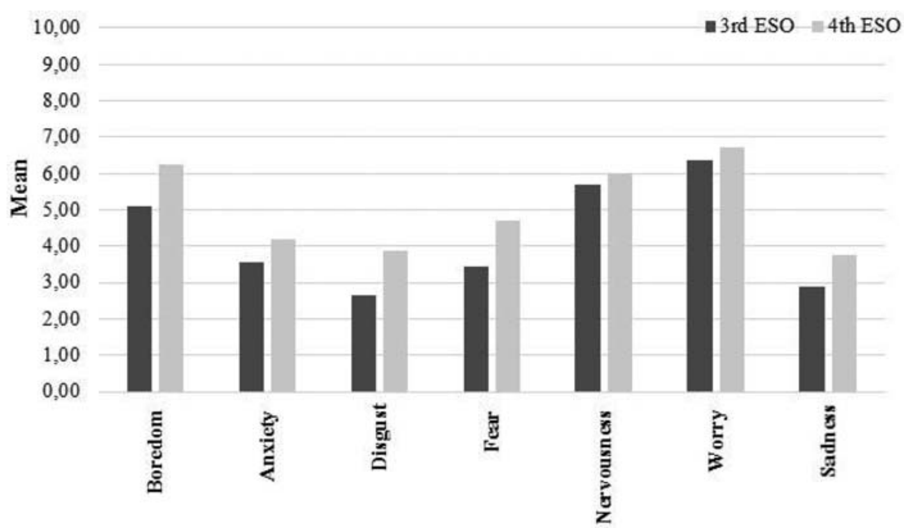

Figure 4 Mean frequency of the negative emotions experienced by secondary pupils when learning physics and chemistry depending on the course.

Conclusions

This study is focused on the comparison between levels (K-9 and K-10) and knowledge content regarding physics and chemistry. The results indicate that, when learning content from the Blocks on Matter (Separation of the elements in a mixture, The states of matter), on Energy and Electricity (Changes of state of matter, Energy and its forms, Heat and temperature) and on Structure and Composition of Matter (Periodic table and periodic properties, Chemical formulation and nomenclature, Chemical reactions and stoichiometry), the secondary education pupils experienced mainly positive emotions. After performing the analysis by levels, it was possible to state out that there is a decline in the frequency of positive emotions when passing from K-9 to K-10.

Moreover, when learning the content of the Physics Blocks of the fourth year, such as Kinematics and Dynamics (Study of motions, Principles of dynamics, Forces – interactions between bodies), and Work and Energy (Kinetic and potential energy, Work and power, Heat and effect of heat on bodies), the pupils experience mostly negative emotions with a high mean frequency. This may be because, during the first three years of secondary education, pupils study chemistry, and on reaching the last year they face physics content for the first time. Other motives could be in the line of the lack of understanding of these topics and the need to try to solve physics problems provokes negative emotions such as boredom, nervousness and worry.

Statistically significant differences are found for both positive and negative emotions.

Thus, in learning physics and chemistry, Secondary Education pupils experience a decrease in the mean frequency of positive emotions such as joy, fun and tranquillity as they pass from third to fourth year. This is very worrying because of the role this last year plays in the decision of further scientific vocations.

There is an increase in the mean frequency of the negative emotions such as boredom, disgust, fear, and sadness when passing from third to fourth year. These emotions need to be taken into account by the teacher for modifying this perception.

There exist several positive correlations, such as the one between the topics of chemistry content and some aspects related to teacher's methods and attitude. In this case, the laboratory activities or the use of TICs improve the pupils' motivation and ability to learn. On the other hand, the exclusive use of the textbook, in the case of teaching physics contents develops a clear correlation towards negative emotions.

These negative emotions are, therefore, due not only to the content or topic, but also to the teacher and the way they give the class (Daschmann et al., 2014). Emotional aspects should be taken into account in order to modify these ineffective ways of teaching.

Notes

1. Affects and emotions are not the same thing and psycological literature usually defines them in a different way. We follow the canonical definition made by Shouse:

   'Although feeling and affect are routinely used interchangeably, it is important not to confuse affect with feelings and emotions. As Brian Massumi's definition of affect in his introduction to Deleuze and Guattari's *A Thousand Plateaus* makes clear, affect is not a personal feeling. Feelings are *personal* and *biographical*, emotions are *social*, and affects are *prepersonal*' (Shouse, 2005). In the current work, we will talk about everything not included in the cognitive sphere, so these are subject of emotional and affective domain.

2. "Causality." Merriam-Webster.com Dictionary, Merriam-Webster, https://www.merriam-webster.com/dictionary/causality. Accessed 18 June 2020.
3. Although an in-depth study of the motivational aspects of this emotional performance should be hard and difficult to carry out, we have chosen a preliminary and simple approach, just for categorize those reasons related to the internal mood disposition of the student.

Acknowledgements

This work was funded by the research projects EDU2016-77007-R (AEI/ERDF, EU), and research project GR18004.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was funded by the research projects EDU2016-77007-R (AEI/ERDF, EU), and research project GR18004.

ORCID

F. Cañada http://orcid.org/0000-0001-5544-0423
D. Airado-Rodríguez http://orcid.org/0000-0002-0632-0481

References

Afolabi, F., & Akinbobola, A. O. (2009). *Constructivist problem based learning technique and the academic achievement of physics students with low ability level in Nigerian secondary schools*. Taylor and Francis.

Angie, A. D., Connelly, S., Waples, E. P., & Kligyte, V. (2011). The influence of discrete emotions on judgement and decision-making: A meta-analytic review. Cognition and Emotion, 25(8), 1393–1422. https://doi.org/10.1080/02699931.2010.550751

Bathgate, M., & Schunn, C. (2017). The psychological characteristics of experiences that influence science motivation and content knowledge. *International Journal of Science Education*, *39*(17), 2402–2432. https://doi.org/10.1080/09500693.2017.1386807

Beauchamp, G., & Parkinson, J. (2008). Pupils' attitudes towards school science as they transfer from an ICT-rich primary school to a secondary school with fewer ICT resources: Does ICT matter? *Education and Information Technologies*, *13*(2), 103–118. https://doi.org/10.1007/s10639-007-9053-5

Bellocchi, A., Quigley, C. F., & Otrel-Cass, K. (2017). *Emotions, aesthetics and wellbeing in science education: Theoretical foundations* (pp. 1–6). Springer. https://doi.org/10.1007/978-3-319-43353-0_1

Bellocchi, A., Ritchie, S. M., Tobin, K., Sandhu, M., & Sandhu, S. (2013). Exploring emotional climate in preservice science teacher education. *Cultural Studies of Science Education*, *8*(3), 529–552. https://doi.org/10.1007/s11422-013-9526-3

Bisquerra, R. (2000). *Emotional education and welfare*. Praxis Ed.

Bisquerra Alzina, R., & Pérez Escoda, N. (2007). Las competencias emocionales (emotional competencies). *Educación XX1*, *10*(0), 61–82. https://doi.org/10.5944/educxx1.1.10.297

Borrachero, A. B., Brígido, M., Costillo, E., Bermejo, M. L., & Mellado, V. (2013). Relationship between self-efficacy beliefs and emotions of future teachers of Physics in secondary education. *Asia-Pacific Forum on Science Learning and Teaching*, *14*(2), 1–11.

Borrachero, A. B., Brígido, M., Dávila, M. A., Costillo, E., Cañada, F., & Mellado, V. (2019). Improving the self-regulation in prospective science teachers: The case of the calculus of the period of a simple pendulum. *Heliyon*, *5*(12), e02827. https://doi.org/10.1016/j.heliyon.2019.e02827

Borrachero, A. B., Brígido, M., Mellado, L., Costillo, E., & Mellado, V. (2014). Emotions in prospective secondary teachers when teaching science content, distinguishing by gender. *Research in Science and Technological Education*, *32*(2), 182–215. https://doi.org/10.1080/02635143.2014.909800

Box, G. E. P., Hunter, J. S., & Hunter, W. G. (2005). *Statistics for experimenters: Design, innovation, and discovery*. Wiley.

Brígido, M., Borrachero, A. B., Bermejo, M. L., & Mellado, V. (2013). Prospective primary teachers' self-efficacy and emotions in science teaching. *European Journal of Teacher Education*, *36*(2), 200–217. https://doi.org/10.1080/02619768.2012.686993

Cañada, F., Sánchez-Martín, J., & Dávila-Acedo, M. A. (2020). Cognitive and emotional learning of chemical reactions. In A. Caamaño (Ed.), *Teaching chemistry. From substances to chemical reactions* (pp. 181–191). Barcelona: Graó.

Cakiroglu, J., Capa-Aydin, Y., & Woolfolk Hoy, A. (2012). Science teaching efficacy beliefs. In Fraser, Barry, Tobin, Kenneth, and Campbell J. McRobbie (Eds.), *Second international handbook of science education* (pp. 449–461). Springer. https://doi.org/10.1007/978-1-4020-9041-7_31

Cheung, D. (2015). Secondary school students' chemistry self-efficacy: Its importance, measurement, and sources. In M. Kahveci & M. K. Orgill (Eds.), *Affective dimensions in chemistry education* (pp. 195–215). Springer. https://doi.org/10.1007/978-3-662-45085-7_10

Chiang, W.-W., & Liu, C.-J. (2014). Scale of academic emotion in science education: Development and validation. *International Journal of Science Education*, *36*(6), 908–928. https://doi.org/10.1080/09500693.2013.830233

Custódio, J. F., Pietrocola, M., & De Souza Cruz, F. F. (2013). Experiências emocionais de estudantes de graduação como motivação para se tornarem professores de física. *Caderno Brasileiro de Ensino de Física*, *30*(1), 25–57. https://doi.org/10.5007/2175-7941.2013v30n1p25

Damasio, A. (1996). *El error de Descartes. Barcelona Crtica*. Booket.

Damasio, A. R. (2012). *Self comes to mind : Constructing the conscious brain*. Vintage Books.

Daschmann, E. C., Goetz, T., & Stupnisky, R. H. (2014). Exploring the antecedents of boredom: Do teachers know why students are bored? *Teaching and Teacher Education*, *39*, 22–30. https://doi.org/10.1016/j.tate.2013.11.009

Davila-Acedo, M. A., Canada, F., Sánchez-Martín, J., & Mellado, V. (2016). Emotions in learning physics and chemistry in secondary education. Students related causes. *Educ. quím*, *27*(3), 217–225. https://doi.org/10.1016/j.eq.2016.04.001 [online]

De Vaus, D. (2013). Surveys in social research. Routledge. https://doi.org/10.4324/9780203519196

Duit, R., & Treagust, D. F. (2012). How can conceptual change contribute to theory and practice in science education? In Fraser, Barry, Tobin, Kenneth, & McRobbie, Campbell (Eds.), *Second international handbook of science education* (pp. 107–118). Springer. https://doi.org/10.1007/978-1-4020-9041-7_9

Garritz, A. (2010). La Enseñanza De La Ciencia En Una Sociedad Con Incertidumbre Y Cambios Acelerados. *Enseñanza de Las Ciencias*, *28*(3), 315–326. http://ensciencias.uab.es/article/view/4/pdf

Goleman, D. D. (1995). Emotional intelligence: Why it can matter more than IQ for character, health and lifelong achievement. Bantam Books. https://doi.org/10.1016/S0962-1849(05)80058-7

Gondim, S. M. G., Pereira, C. R., Lúcia, A., Hirschle, T., Silva Palma, E. M., Alberton, G. D., Paranhos, J., Santana, V., Raquel, W., & Ribeiro, B. (2015). Validation evidences of a measure of personal characteristics of emotional regulation. *Psychology/Psicologia Refl Exão e Crítica*, *28*(4), 659–667. https://doi.org/10.1590/1678-7153.201528403

Gray, D. L. L. (2017). Is psychological membership in the classroom a function of standing out while fitting in? Implications for achievement motivation and emotions. *Journal of School Psychology*, *61*, 103–121. https://doi.org/10.1016/j.jsp.2017.02.001

Kahveci, M., & Orgill, M. K. (2015). Affective dimensions in chemistry education. Springer. https://doi.org/10.1007/978-3-662-45085-7

Kelly, G. J., McDonald, S., & Wickman, P. O. (2012). Science learning and epistemology. In Fraser, Barry, Tobin, Kenneth, & McRobbie, Campbell (Eds.), *Second international handbook of science education* (pp. 281–291). Springer. https://doi.org/10.1007/978-1-4020-9041-7_20

King, D., Ritchie, S., Sandhu, M., & Henderson, S. (2015). Emotionally intense science activities. *International Journal of Science Education*, *37*(12), 1886–1914. https://doi.org/10.1080/09500693.2015.1055850

Laukenmann, M., Bleicher, M., Fuß, S., Gläser-Zikuda, M., Mayring, P., & von Rhöneck, C. (2003). An investigation of the influence of emotional factors on learning in physics instruction. *International Journal of Science Education*, *25*(4), 489–507. https://doi.org/10.1080/09500690210163233

Lavega, P., Alonso, J. I., Etxebeste, J., Lagardera, F., & March, J. (2014). Relationship between traditional games and the intensity of emotions experienced by participants. *Research Quarterly for Exercise and Sport*, *85*(4), 457–467. https://doi.org/10.1080/02701367.2014.961048

LeDoux, J. E. (2000). Emotion circuits in the brain. *Annual Review of Neuroscience*, *23*(1), 155–184. https://doi.org/10.1146/annurev.neuro.23.1.155

Mellado, V., Borrachero, A. B., Brígido, M., Melo, L. V., Dávila, M. A., Cañada, F., Conde, M. C., Costillo, E., Cubero, J., Esteban, R., Martínez, G., Ruiz, C., Sánchez, J., Garritz, A., Mellado, L., Vázquez, B., Jiménez, R., & Bermejo, M. L. (2014). Emotions in science teaching. *Ensenanza de Las Ciencias*, *32*(3), 11–36. https://doi.org/10.5565/rev/ensciencias.1478

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, *25*(9), 1049–1079. https://doi.org/10.1080/0950069032000032199

Pekrun, R. (1992). The impact of emotions on learning and achievement: Towards a theory of cognitive/motivational mediators. *Applied Psychology*, *41*(4), 359–376. https://doi.org/10.1111/j.1464-0597.1992.tb00712.x

Pekrun, R., & Linnenbrink-Garcia, L. (2014). *International handbook of emotions in education*. Taylor and Francis.

Posner, J., Russell, J. A., & Peterson, B. S. (2005). The circumplex model of affect: An integrative approach to affective neuroscience, cognitive development, and psychopathology. *Development and Psychopathology*, *17*(3), 715–734. https://doi.org/10.1017/S0954579405050340

Rahayu, S. (2015). Evaluating the affective dimension in chemistry education. In M. Kahveci, & M. K. Orgill (Eds.), *Affective dimensions in Chemistry education* (pp. 29–49). Springer. https://doi.org/10.1007/978-3-662-45085-7_2

Robles, A., Solbes, J., Cantó Doménech, J., & Lozano Lucía, Ó. (2015). Actitudes de los estudiantes hacia la ciencia escolar en el primer ciclo de la Enseñanza Secundaria Obligatoria. *REEC: Revista Electrónica de Enseñanza de Las Ciencias*, *14*(3), 361–376.

Sanchez-Martin, J., Alvarez-Gragera, G. J., Davila-Acedo, M. A., & Mellado, V. (2017). Teaching technology: From knowing to feeling enhancing emotional and content acquisition performance through Gardner'S multiple intelligences theory in technology and design lessons. *Journal of Technology and Science Education*, *7*(1), 58. https://doi.org/10.3926/jotse.238

Schunk, D. H., & Usher, E. L. (2011). *Assessing self-efficacy for self-regulated learning: The university of North Carolina at Greensboro university of Kentucky* (pp. 296–311). Taylor and Francis. https://doi.org/10.4324/9780203839010-25

Schutz, P. A., & Zembylas, M. (2009). Advances in teacher emotion research: The impact on teachers' lives. In *Advances in teacher emotion research: The impact on teachers' lives*. Springer. https://doi.org/10.1007/978-1-4419-0564-2

Shouse, E. (2005). Feeling, emotion, affect. *M/C Journal*, *8*(6), https://doi.org/10.5204/mcj.2443

Sinatra, G. M., Broughton, S. H., & Lombardi, D. (2014). Emotions in science education. In R. Perkun, & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education*. Taylor and Francis.

SPAIN. (2007). *Royal Decree 83*/2007.

Thagard, T. (2008). Conceptual change in the history of science: Life, mind and disease. In S. Vosniadow (Ed.), *International Handbook of research on concpetual change* (pp. 374–387). Routledge.

Tobin, K. (2010). Reproducing and transforming science teachin in a collaborative atmosphere. *Enseanza de Las Ciencias*, *28*(3 SRC-BaiduScholar FG-0), 301–313.

Tobin, K. (2012). Sociocultural perspectives on science education. In Fraser, Barry, Tobin, Kenneth, & McRobbie, Campbell (Eds.), *Second international handbook of science education* (pp. 3–17). Springer. https://doi.org/10.1007/978-1-4020-9041-7_1

Tomas, L., & Ritchie, S. M. (2012). Positive emotional responses to hybridised writing about a socio-scientific issue. In *Research in science education* (Vol. 42(1), pp. 25–49). https://doi.org/10.1007/s11165-011-9255-0

Trigwell, K., Ellis, R. A., & Han, F. (2012). Relations between students' approaches to learning, experienced emotions and outcomes of learning. *Studies in Higher Education*, *37*(7), 811–824. https://doi.org/10.1080/03075079.2010.549220

Tyng, C. M., Amin, H. U., Saad, M. N. M., & Malik, A. S. (2017). The influences of emotion on learning and memory. In *Frontiers in Psychology* (Vol. 8(Aug)). Frontiers Media S.A. https://doi.org/10.3389/fpsyg.2017.01454

Usher, E. L., & Pajares, F. (2008). Self-efficacy for self-Regulated learning. *Educational and Psychological Measurement*, *68*(3), 443–463. https://doi.org/10.1177/0013164407308475

Van Der Wal, C. N., & Kowalczyk, W. (2013). Detecting changing emotions in human speech by machine and humans. *Applied Intelligence*, *39*(4), 675–691. https://doi.org/10.1007/s10489-013-0449-1

Van Uum, M. S. J., Verhoeff, R. P., & Peeters, M. (2016). Inquiry-based science education: Towards a pedagogical framework for primary school teachers. *International Journal of Science Education*, *38*(3), 450–469. https://doi.org/10.1080/09500693.2016.1147660

Wan, Z. H., & Lee, J. C. K. (2017). Hong Kong secondary school students' attitudes towards science: A study of structural models and gender differences. *International Journal of Science Education*, *39*(5), 507–527. https://doi.org/10.1080/09500693.2017.1292015

Wang, H., & Hall, N. C. (2018). A systematic review of teachers' causal attributions: Prevalence, correlates, and consequences. In *Frontiers in psychology* (Vol. 9(DEC), pp. 2305). Frontiers Media S.A. https://doi.org/10.3389/fpsyg.2018.02305

Wickman, P.-O. (2017). *Back to the drawing board: Examining the philosophical foundations of educational research on aesthetics and emotions* (pp. 9–37). Springer. https://doi.org/10.1007/978-3-319-43353-0_2

Zhang, S., & Zhao, X. (2013). Dimensionality reduction-based spoken emotion recognition. *Multimedia Tools and Applications*, *63*(3), 615–646. https://doi.org/10.1007/s11042-011-0887-x