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Scientific practices in teacher education: the interplay of sense, sensors, and emotions

Maria Rut Jimenez-Liso, María Martinez-Chico, Lucy Avraamidou, and Rafael López-Gay Lucio-Villegas

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ABSTRACT

Background: In response to reform recommendations calling for students’ engagement in scientific practices and the lack of the enactment of such practices in science classrooms, we explored the implementation of scientific practices with special emphasis on model-based inquiry in a secondary science teacher preparation program.

Sample: The participants of this study were 26 preservice secondary teachers who engaged in a specially designed sequence that emphasized scientific practices.

Purpose: Our aim in this study was to examine the impact of this specially-designed sequence on the participants’ views about the usefulness of scientific practices as a pedagogical approach, their intentions in implementing scientific practices as future teachers, and the nature of the emotions they experienced throughout their engagement in the sequence.

Design and methods: Data were collected through a questionnaire, which the participants completed following their participation in the sequence.

Results: The statistical analysis of the data showed that the majority of the participants: (a) perceived that they developed adequate understandings about scientific practices; (b) stated that they would implement scientific practices in their future teaching practices; and, (c) experienced positive emotions throughout their engagement in the sequence.

Conclusion: These findings are discussed alongside implications for teacher preparation and future research in the area of scientific practices and emotions.

KEYWORDS

Scientific practices; emotions; teacher education; models & modelling

Introduction

The recommendations for reform in science education proposed in the Report to the European Commission of the expert group on science education ‘Science Education for Responsible Citizenship’ (EC 2015) and the National Research Council in North America (NRC 2015) emphasize that all citizens should have a better understanding of science and technology if they are to participate actively and responsibly in science-informed decision-making and knowledge-based innovation. Central to these reform
recommendations is a scientific inquiry, which refers to students’ engagement in asking scientifically oriented questions, setting investigations, collecting and analysing data, formulating explanations based scientific evidence (Avraamidou and Zembal-Saul 2010; Alake-Tuenter et al. 2012; Crawford 2014; Howes, Lim, and Campos 2009).

These recommendations have been adopted and studied in various classrooms in different places of the world (e.g., USA, Spain, Cyprus, Ireland, etc.). However, the emphasis on teaching science as a process of inquiry found in the National Science Education Standards (National Research Council 1996) has generated dissatisfaction due to a confusion between the ‘goal of science’ with the ‘goal of learning science’, and the lack of a commonly shared understanding of what teaching science through inquiry means (Osborne 2014). As a matter of fact, an emphasis on ‘scientific inquiry’ often times is translated as an emphasis on the practical engagement of children with science, predominantly on the manipulative skills for successful experimentation while ignoring their conceptual engagement and the understanding about inquiry and its role in science (Osborne 2014). As a response, two years later, the National Research Council in North America with a newly published report (2012) advocated for the use of ‘scientific practices’ which emphasizes the importance of engaging students in the following practices:

- Asking questions
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information (p. 41)

Osborne (2014) argued that these scientific practices only have value if they: (a) help students to develop a deeper and broader understanding of what we know, how we know what we know, and the epistemic and procedural constructs that guide the practice of science; (b) they are a more effective means of developing such knowledge; and (c) they present a more authentic picture of the endeavour that is science. However, teachers need to experience scientific practices as learners themselves before they become able to implement those in their instructional practices (Ferrés i Gurt, Marbà Tallada, and Sanmartí Puig 2015; Haefner and Zembal-Saul 2004). Thus, an important aspect of preparing teachers to implement scientific practices is to provide them with experiences that will enable them to construct ideas about science teaching that include scientific, epistemic, and pedagogical aspects of learning. With this goal as a departure point, we designed our science teacher preparation program in ways that support teachers to develop contemporary ideas about science teaching and learning through scientific practices (Martínez-Chico et al. 2018) while paying emphasis on learning by doing (Haefner and Zembal-Saul 2004) and reflecting on the learning process.

Aspects related to science engagement are statistically significantly and positively related to science achievement while science teaching practices as for example, modelling, can offer mechanisms for enhancing aspects of science engagement (Grabau and Ma 2017). In teacher education, as Tobin and Ritchie (2012) the experience of emotions of pre-service
teachers are related to their self-efficacy and confidence as future teachers. Yeigh et al. (2016) explored the links between becoming aware of what is being felt (emotions) and trust in teaching, emphasizing that in order to fully understand learning, we must consider affective measures that help identify those cognitive-emotional aspects of learning that impact on aspects such as interest, perseverance in the face of difficulty or the ability to consider the ideas of others and participate in a critical and constructive manner. Grounded within these arguments, in this study we explore the interplay between the engagement of preservice science teachers in scientific practices and the emotions experienced throughout the learning process.

A review of the literature indicates that the knowledge base about the implementation of scientific practices in school classrooms as well as teacher preparation is quite limited (Arias et al. 2016; Cobern et al. 2010; Osborne 2014). In attempting to address this gap in the literature, in this paper we report on the design, implementation, and evaluation of a specially designed sequence in the context of secondary science teacher preparation program which emphasizes scientific practices. Specifically, the research questions that guided this study are the following:

- What is the impact of a specially designed sequence on preservice teachers’ views about scientific practices and their intention in implementing scientific practices as future teachers?
- What is the nature of preservice teachers’ emotions throughout their engagement in the sequence?

With the dual aim of overcoming the dissociation ‘practical-theoretical contents learning’ commonly assumed by teachers, and making preservice teachers’ aware of what they can learn (models) and feel, we aimed at supporting preservice teachers in experiencing scientific practices through an integrated set of *hands-on* and *minds-on* activities. With this goal in mind, we designed a sequence of activities about a daily phenomenon (i.e., adding salt on a snowy road) that follows an integrated Inquiry and Modelling-based Science Education approach, implemented in the training of a group of teachers (n = 26) in a Secondary Teaching Master Degree programme in a period of a year in Southern Europe. In doing so, we aimed to achieve the following goals:

(a) Engage preservice teachers in scientific practices in the context of a model-based inquiry sequence for the purpose of experiencing them as learners before they consider using them as teachers

(b) Support preservice teachers in reflecting on what they learn, how they learn, and identifying the emotions they experienced through their engagement in a model-based inquiry sequence

(c) Support preservice teachers in recognizing the benefits of the use of scientific practices as an alternative pedagogical approach

In the next section, we present the theoretical framework upon which the teaching approach was developed and we discuss the related literature.
Theoretical and empirical underpinnings

Scientific practices

For the purpose of this study, we conceptualize scientific practices as the processes that allow the construction of scientific knowledge, theories and models using evidence and the communication of scientific knowledge through the construction of arguments (Garrido Espeja 2016; Osborne 2014). In emphasizing model-based inquiry, we envision that implementing scientific practices in science teaching might support students to not only developing an understanding of the disciplinary core ideas, but to also develop procedural and epistemic understandings. What this means essentially is that scientific practices provide a means to not only guide the process of science learning but to also support students in developing an understanding about how science works (Osborne 2014).

Reform documents emphasize the importance of implementing scientific practices to make science accessible to citizens and help them to understand the epistemic basis of science (NRC 2012). Scientific practices are cognitive, discursive and social activities carried out in science classrooms that are embattled to develop epistemic understanding and appreciation of the nature of science, and include among others: addressing questions, developing and using models, engaging in arguments, constructing and communicating explanations based on evidence (Adams et al. 2018).

Model-based inquiry in teacher education

Given the fact that teachers’ knowledge, conceptions, beliefs about teaching have been shown to influence classroom practices (Avraamidou and Zembal-Saul 2010), we argue that it is important to examine preservice teachers’ knowledge and beliefs when designing teacher preparation courses. Following on our previous work and acknowledging a limitation to methodological makes clear-cut distinctions between the two constructs, we fold knowledge and beliefs together (Avraamidou and Zembal-Saul 2010). However, we also use the construct of ‘perceptions’ to refer to the attitudes of preservice teachers about the usefulness of scientific practices and their intentions to enact scientific practices as future teachers.

As further research has been recommended to illustrate specific characteristics and components of such effective teacher education programs that contribute to the development and use of teacher knowledge (Avraamidou and Zembal-Saul 2010), our work is focused on the design and evaluation of short sequences of activities to promote preservice teachers’ knowledge about inquiry-based teaching.

From the purpose of this study, we conceptualize school scientific models (the models that are found in the school curriculum) as adequate school versions of the scientific models (used by the scientific community), which are theoretical and conceptual in nature, and which have the ability to allow students to describe, explain, predict and intervene in a large number of world phenomena from a certain ‘way of looking’ (Izquierdo-Aymerich and Adúriz-Bravo 2003; Hernández, Couso, and Pintó 2015). The process of building models is defined as modelling (Garrido Espeja 2016; Hernández, Couso, and Pintó 2015; Schwarz and Gwekwerere 2007; Windschitl, Thompson, and Braaten 2008) and it is part of the
scientific practices framework (Osborne 2014). Participation in these practices, in addition to contributing to the construction of key models, allows students to learn about science and its nature through activities that resemble real scientific work.

In designing this study, we were interested in engaging preservice teachers in scientific practices, such as explicit expression of their mental models, use of their models to predict or explain phenomena, evaluation of their models based on the available evidence and review of their models based on new ideas (Garrido Espeja and Couso Lagarón 2017; Garrido Espeja 2016; Soto-Alvarado, Couso, and Lopez-Simó 2019), understood as a process, both personal and social, of ‘giving meaning to ideas in development’ (Schwarz et al. 2009, 637). Windschitl, Thompson, and Braaten (2008) pointed out that the incorporation of models in the school classrooms remains scarce. In attempting to address this issue, we follow on Garrido Espeja’s (2016) recommendation to incorporate these aspects in the initial teacher training, as it is essential that future teachers participate in activities of inquiry. Such activities can serve as good examples for preservice teachers, through experiencing those as learners, which is essential before they are able to apply it in the future to their classes (Martínez-Chico et al. 2018; Wilson and Berne 1999).

What becomes clear in the above is that in order to successfully develop conceptual understandings in science, it is necessary to engage learners in reflecting on and discussing their understandings of scientific concepts as they are developing them, as well as constructing and critiquing their own models. In fact, an understanding of science models and the modelling process enables students to develop a metacognitive awareness of knowledge development within the science community as well as providing the tools to reflect on their own scientific understanding (Coll, France, and Taylor 2005).

Grounded within these ideas, for the purpose of this study we designed a sequence of scientific practices through an integrated Model-Based Inquiry (MBI) approach, in which PSTs experience this approach as learners and reflect on the experience as thinkers. It is hence important to consider the different interpretations of inquiry and the existence of a disagreement about what inquiry teaching actually entails (Crawford 2014; Osborne 2014) and some myths about inquiry, such as: students’ engagement in hands-on activities guarantees that inquiry learning is occurring, or inquiry teaching occurs easily through the use of hands-on or kit-based instructional materials. Even though the framework for science education from a MBI perspective offers an appropriate framework for school science investigations, it must be translated into concrete terms, specifying the kind of activities we would include in our designs, to avoid misunderstandings mentioned above. The MBI approach that we adopted emphasizes the following: involving students in the generation, testing, and evaluation of scientific models, so that they understand not only the epistemic features of scientific knowledge, but also the scientific concepts and the practice of modelling and argumentation (Windschitl, Thompson, and Braaten 2008). This model-based approach can be actualized through the proposed structure of Erduran and Dagher’s (2014) heuristic analysis of the range of scientific practices that bring together the epistemic, cognitive, and social-institutional aspects of science. These researchers have developed a representation of the scientific practices where each epistemic and cognitive aspect are represented on the edge of an ‘Benzene Ring’, with the social content and practices represented by the
diffuse pi bond in the internal ring structure. This framework was used as the basis for the design of the sequence, which addressed epistemic goals, cognitive goals and social aspects of science through the exploration of the main driving question.

**Emotional engagement and learning**

An examination of the cognitive, procedural and affective engagement has been of interest in educational research for at least a decade (Appleton, Christenson, and Furlong 2008; Fredricks et al. 2016; Funk and Parker 2018; Pekrun et al. 2002). The concern for the decrease in the interest of students at higher levels (with respect to Infant and Primary) indicated by Murphy and Beggs (2003) and Pell and Jarvis (2001) up to the present, where greater emphasis is placed on the emotions felt, expressed or remembered towards the sciences (Brigido et al. 2013; Mellado et al. 2014) or the emotions felt in a group and the classroom climate (Belloccchi et al. 2014). There is another way of supporting learners’ emotional engagement that goes beyond feeling happy, sad, angry, or concerned about aspects of science. That is to engage students in exploring their emotions about each other and about science as well for the purpose of supporting them in improving their social and emotional skills (Matthews 2004). This is precisely how we aimed at supporting preservice teachers’ emotional engagement in this study.

The importance of examining the kinds of emotions experienced in educational settings has been recognized by researchers in different fields such as social and developmental psychology, sociology and education. For both students and teachers, educational settings are of critical importance in the formation of emotions. Lots of hours are spent in the classroom, lots of social relationships are established, and the attainment of goals depends on individual and collective means in educational settings, which are infused with intense emotional experiences that direct interactions, affect learning and performance, and influence personal growth in both students and teachers (Schutz and Pekrun 2011). The question then is how emotions might impact learning? Evidence from the literature suggests that sustained learning is a complex phenomenon comprising a myriad of processes, such as those involved in perceptual-cognitive appraisals, affective responses, fulfilling motivational goals, striving future goals and self-regulation (Turner & Waugh, in Schutz and Pekrun 2011). Hence, emotions become an integral part of the process of science learning and learning of how to teach science. Spector, Burkett, and Leard (2007) reported that all pre-service teachers learning science, and learning to teach science, might progress through the same stages, such as strong emotions, resistance, surrender, and acceptance. Because teachers invest emotionally and intellectually in their beliefs, they seek to maintain them unless these beliefs are adequately challenged (Alake-Tuenter 2014). It is hence crucial to engage preservice teachers in experiences that not only support them in understanding the advantages of the use of scientific practices as a pedagogical approach but also provide opportunities for emotional engagement.

As a matter of fact, the importance of emotions in both cognitive and affective processes is one of the aspects of conceptual change (Thagard 2008) and thus, as stated Mellado et al. (2014), the teachers who ignore these affective aspects may be limiting the conceptual change in their students. As Nicolaou, Evagorou, and Lymbouridou (2015)
reported, a number of studies in science education state provide evidence that positive emotions and enjoyment from learning science plays a significant role in learning outcomes and serve as a driving force for self-learning, and for retaining knowledge (Alsop and Watts 2003). Nevertheless, as we described in the introduction of the paper, the analysis of preservice teachers’ emotions about learning science through participating in authentic contexts is still scarce, despite a wealth of evidence pointing to the fact that emotions, either positive or negative, can have a significant impact on learning (Dávila et al. 2015; Nicolaou, Evagorou, and Lymbouridou 2015). Dávila et al. (2015) work with a confidence level of 95% for the development of their model which included different kinds of emotions, such as, joy, trust, happiness, enthusiasm, surprise, shame, concern, etc.

Despite research evidence pointing to the prominent role of emotions in learning, researchers examining scientific practices have largely focused on the cognitive aspects of learning. However, there is much to be learned about how students enter into and sustain their engagement in these practices (Jaber and Hammer 2016), and even more in the context of teacher education (Grauer 2014). As science-based learning processes, scientific practices are not merely cognitive but are highly charged with feelings and self-regulation they should not be reduced to metacognitive aspects, but also be extended to the affective dimensions (Costillo Borrego et al. 2013). As research has shown, in any given cognitive environment, as for example, engagement in scientific practices, affective constructs like attitudes, emotions, interest and beliefs are key factors that affect students’ self-efficacy and pursuit of science courses (Rice et al. 2013). All these affective constructs may serve as multiple lenses to view the manner in which appropriate actions can be undertaken to improve students’ learning.

For the purpose of this study, we turned out attention to the following kinds of emotions: Rejection, Concentration, Insecurity, Interest, Boredom, Confidence, Satisfaction, Dissatisfaction, and Shame. We chose to focus on these emotions and not others based on research findings pointing to their relevance to learning and based on the findings of a pilot study for the purpose of avoiding overlap of confusion between similar types of emotions (Martínez-Chico et al. 2017). In addition, we examined the kinds of emotions that the combination of the above kinds of emotions might produce, as for example, anger as a product of rejection and dissatisfaction. These emotions were selected based on an adapted version of the Borrachero Cortés et al. (2015) framework. We selected only those emotions that are more understandable and clearly differ from the others, avoiding overlapping, and excluding those emotions, such as love or hatred, which we consider irrelevant to science education activities (Martínez-Chico et al. 2017). In agreement with Mellado et al. (2014) we recognize that a relevant intervention is not synonymous with success if these emotions are not identified, and it may be that, as it happens with knowledge, different emotions can go unnoticed, leading to negative attitudes, anger, or even to the rejection of science. Therefore, we posit that science learning should also produce emotions, which may produce to a greater or lesser extent different kinds of emotions. In this study, we were interested in supporting preservice teachers develop an awareness of the emotions they experienced as they engaged in the sequence.
Context

Overview and purpose of the sequence

In the context of this study we began the cycle of the sequence from the ‘Real World’ because our preservice teachers were engaged in the main driving question of the sequence: Why do we spread salt on the roads when it snows? Once the preservice teachers would respond by explaining what they think are the causes, we would orient the teaching towards the realization of predictions (‘Prediction’) about what they think will happen to the temperature when we spread salt in the snow. We required that the preservice teachers would provide an ‘Explanation’ about the reasons that the temperature rises or falls. In order to support preservice teachers in understanding the internal structure of matter, we asked them to imagine what matter is made of, a discussion which led us to introduce a model (the Molecular Kinetic Theory, MKT). Once preservice teachers would discuss, argue, and offer a justification (relying on the model or not), more complex answers were elicited. Following on that, preservice teachers would make observations about the phenomena after designing the experiments to collect the necessary ‘data’ that would allow them to check their predictions and revise the stated explanations. After that, preservice teachers would perform ‘Activities’ (mainly hands-on) with sensors and obtain results that compare with what they thought initially. The preservice teachers would then rely on that data to try to answer the question that initiated the sequence. The data obtained, would encourage preservice teachers to reason and a new and more completed Model can be introduced to complete their explanations and/or help them to re-formulate their previous ‘Models’, by constructing a model that could be used to explain other different phenomena or situations. In engaging preservice teachers in these activities, we addressed all epistemic, cognitive, and social-institutional aspects of science, which were explicitly discussed during the teaching sequence.

Description of the sequence

In this section, we describe each step of the sequence. The sequence is composed of eight activities with duration of 1 h30 min. A first version of the sequence had been implemented and evaluated with 26 PST in a Secondary Teaching Master Degree programme over the course 2014–2015. In the section that follows we will present the results of the evaluation of the sequence effectiveness in this latter group. The teaching sequence places PSTs as learners (they experience the learning of scientific contents through scientific practices) and as thinkers (the reflect on the process experienced, the conceptual and procedural contents learned and the emotions felt). For all activities, the participants were expected to work in small groups (4–5) and they were provided with a script with the scheme of the sequence where they write their answers to the various activities (Table 1). The central driving question of the sequence was the following: Why do we spread salt on the roads when it snows?
Table 1. Teaching sequence.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Description/justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity 1. Usually, when it snows, the snowplough adds salt to the roads. What do you think that happens? Describe it.</td>
<td>As learning is essentially a matter of creating meaning from the real activities of daily living, with this activity we try to embed the scientific contents in the ongoing experiences of the learners, creating opportunities for learners to approach these contents in the context of real-world challenges. In that way, contextualizing in a real-world situation, learning occurs from the classroom through the real practice experience and vice versa, so that students get involved in looking for explanations of known phenomena that make sense to them. The answers that usually appear are: to increase friction and prevent cars from slipping, to melt the snow . . . Then the students are asked for more concrete responses through the following question.</td>
</tr>
<tr>
<td>Activity 2. What do you think will happen to the temperature when salt is spread? Make predictions and justify them.</td>
<td>The purpose is to make them predict and justify their ideas. Although all kind of responses are given, the most common is the temperature increases, because salt is corrosive, or because it produces a chemical reaction that dissolves the snow . . . Now we wonder if these models or explanations are useful for us to explain their predictions.</td>
</tr>
<tr>
<td>Activity 3. Do your explanations or models really explain what happens to the temperature?</td>
<td>To deepen the need to justify their hypotheses so that they were coherent and explained their predictions properly, we propose using not just experiential knowledge, and so we introduce Kinetic Molecular Theory (KMT). This can be used as a model that can be useful to justify their initial hypotheses, so we wonder if this model serves to explain the phenomenon. Ideas related with temperature and its relation to the vibration rate of molecules, phase changes, etc., are discussed in the classroom. After this necessary debate, and once they have explicitly formed their models to explain what they think happens to the temperature and why, we proceed to look for evidence, focusing the inquiry on the temperature variation.</td>
</tr>
<tr>
<td>Activity 4. How would you know if your hypothesis fits the reality? Let’s look for evidence to check it!</td>
<td>The students are asked to suggest different ways to measure the temperature. This is a good opportunity to work on some strategies of scientific enquiry such as the need to keep one factor constant and vary the other when controlling variables, etc. After listening to their proposals, we can show the materials that we have to operationalize a design and implement it in the classroom: glasses with ice, salt, temperature sensors connected to the computer. As well as considering and collecting data of temperature, we have to find out if the salt effect supposes an increase in the speed of melting ice, so to prepare a 'blank solution' with a sensor (a glass only with ice) is proposed.</td>
</tr>
<tr>
<td>Activity 4.1. Represent graphically your prediction on the variation of the temperature when salt is added to ice</td>
<td>Before data collection, the software used allows for graphic representation of the evolution estimated for the variable. It may be interesting to work on the interpretation of graphs from the different predictions, identifying the initial temperature (ice temperature), the melting/freezing temperature, the evolution expected (increases or decreases), and the rate of change, the highest/lowest temperature it will reach . . .</td>
</tr>
</tbody>
</table>
### Table 1. (Continued).

<table>
<thead>
<tr>
<th>Activities</th>
<th>Description/justification</th>
<th>‘Benzen Ring corner’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity 4.2. Collect data to test hypotheses</td>
<td>Furthermore, Science includes activities such as experimentation and/or observation, which enable the generation of data and subsequently the consideration of evidence to construct and review models and explanations (Easterday, Rees Lewis, and Gerber 2016). Therefore, students implement the experimental design and initiate the data collection, which will be represented numerically and graphically in real time. Students perform ‘Activities’ using sensors and obtain results that compare with what they thought initially.</td>
<td></td>
</tr>
<tr>
<td>Activity 5. Observe what happens and analyze the results</td>
<td>Does the ice (without salt) melt before the ice with salt? Does the ice temperature go up or down when you add salt? At what temperature? What temperature does it reach? What about the amount of melted ice: Does the glass only with ice has more liquid water or it is the one with ice plus salt? Does it match what you expected? Once the PSTs observe the results in the graph, we propose these questions to facilitate the data analysis. The sudden drop in temperature (which can reach $-17.4^\circ$C) generates a big surprise, especially when comparing the results with what they predicted. The drop-in temperature when salt is added is short, but data should be collected for 5 or 10 minutes until the minimum temperature is reached. Again, the participants are surprised by the fact that despite the sudden drop in temperature, the glass with the mixture ice-salt has almost completely melted while the glass only with ice has not.</td>
<td></td>
</tr>
<tr>
<td>Activity 6. Synthesis and review of explanations</td>
<td>The evidence obtained from data can contribute to review their explanations and/or models. Then, if the salt lowers the temperature of ice water to $-10^\circ$C, why is salt added when it snows? As the majority hypothesis is that the salt ‘melts because it increases the temperature of the snow,’ when they realise that it actually decreases, it becomes necessary to justify why salt is added to snow and to rethink an explanation of what happens. Indeed, salt is sprinkled because it makes ice and snow melt faster, but … why does this happen? We need a model that allows us to explain it. Now, we begin a new section (explicative) about the question: Why salt facilitates the ice melting at so low temperatures?</td>
<td></td>
</tr>
<tr>
<td>Activity 7. Can we explain why salt facilitates the melting of ice at such low temperatures? We need a model to explain …</td>
<td>These comments are developed below, in the main text of the document.</td>
<td></td>
</tr>
<tr>
<td>Activity 8. This SensoPill, has made sense to you? What have you learned and felt?</td>
<td>Self-regulation of learning and emotions are performed. More comments are added in the main text of the document.</td>
<td></td>
</tr>
</tbody>
</table>
Participants

The context of this study is defined by a compulsory master’s degree to become a Secondary school teacher, at a public university following a two-semester academic calendar. The course of this master’s program is 90 h developed throughout 4 months, and includes as much 10 instructional hours per week, with two practices terms in between. The course is designed upon recommendations for reform, especially in the context of the framework Science Education for Responsible Citizenship (EC 2015) and the PISA 2015 framework which emphasizes the following competencies related to scientific practices: Explain Phenomena Scientifically, Evaluate and Design Scientific Enquiry, and Interpret Data and Evidence Scientifically (OECD 2016).

The participants of the study were 26 pre-service teachers: 13 men and 13 women. These were enrolled in a postgraduate master’s degree called Secondary Science Teachers Training, which is compulsory for earning a certification for secondary school teaching in the country that defined the context of this study.

As part of the course, the participants were provided with multiple opportunities to examine and re-examine their developing ideas about science teaching and learning. These include activities in the classroom as well as course assignments for the practical terms, which aim at providing participants with opportunities to reflect on science and the scientific activity, the purpose of teaching science, their learning experiences at the school and the current ones, the traditional science teaching approaches effectiveness, their roles as science teachers, as well as their ideas about science teaching and learning.

Within the country context in which this study took place, scientific practices and teaching approaches that can promote them (such as Model-Based Inquiry) are practically absent in Pre-service Secondary School teachers (from now PST) training. Hence, at the time the participants enrolled in the master’s program they had never experienced inquiry-based sequences as part of this course. Nevertheless, this is the fourth cycle of inquiry that they experience in the course, which limits the possibility that the findings of this study are influenced by the novelty factor. Prior to the implementation of this sequence, we had implemented other inquiry-based sequences on other science contents related to the Sun-Earth model, to the floating of objects and the model of a living being. Therefore, the possible positive effect is not because this is the first cycle of inquiry they experience, so that they find hands-on and minds-on inquiry learning more appealing.

In previous-related research we found that in-service secondary school teachers do not hold sophisticated understandings of scientific practices, they are not aware of the advantages of implementing scientific practices, and they only consider the increase of student motivation as the main outcome of developing scientific practices in their classrooms, leaving out those related to promoting theoretical contents learning such as models (Jiménez-Liso et al. forthcoming). This is in agreement with the findings of Fitzgerald, Danaia and McKinnon’s study (2017) which provided evidence that enhancing student motivation is the main driving force for teachers to implement scientific practices. As far as the role of emotions in learning is concerned, various studies have revealed that emotions are connected to various dimensions of student learning including motivation, learning strategies, learning
outcomes, and achievement which is suggestive of the potential connections between classroom emotions and the quality of classroom experiences (Pekrun and Stephens 2012). Preservice teachers’ emotions and how they relate to teaching and learning remains an unexplored research area even though there exists ample evidence that students’ emotions, either positive or negative, have a significant impact on learning (Dávila et al. 2015; Nicolaou, Evagorou, and Lymbouridou 2015). As a matter of fact, there exists a wealth of evidence that shows the quality of education is related to classroom emotions (Bellocchi, Quigley, and Otrel-Cass 2017; Schutz, Aultman, and Williams-Johnson 2009) and so we cannot ignore the relation teaching approach-emotions-learning. Therefore, in this study, we pay attention to preservice teachers’ emotions while we explore their understandings of scientific practices as a pedagogical approach as they experience scientific practices as learners.

Methods

Design processes

As described earlier, the teaching sequence was implemented in a course with 26 participants. The participants were informed about the fact that they were selected to participate in this research study and they authorized their participation and the collection of all research data. The 90-h course consisted of three parts that aimed to achieve three goals:

(a) To engage preservice teachers in short inquiry-based sequences and reflect on the changes identified in their understandings of scientific practices;
(b) To support preservice teachers in developing the knowledge and skills needed to design and implement inquiry-based sequences in secondary schools in the future;
(c) To support preservice teachers in evaluating the implementation of inquiry-based sequences in regards to their effect on students’ emotions and learning.

Data collection

The teaching sequence was implemented in the first part of the course. In order to achieve the goal of supporting preservice teachers to recognize what they have learned, how they have learned it, and the emotions they experienced, we developed a questionnaire that includes a KPSI (Knowledge Previous Students Inventory) (Tamir and Amir 1981) and various emotions that can be experienced during learning experiences. This is a post-experimental design and its purpose is to generate outcomes that can later be tested with more systematic designs (Bisquerra Alzina and Pérez Escoda 2007). In particular, it is a post-only design with a group of preservice teachers, because what we are interested in examining how the participants’ perceived their engagement in the intervention, what they learned, and what emotions they experienced throughout the intervention. One limitation of the fact that we only used a questionnaire as a means for data collection is that the participants’ responses are self-reported. Collecting
additional data through interviews would have helped to address this issue, however, this was not possible because of constraints related to time and resources.

The questionnaire design responds to the structure of a Knowledge and Prior Study Inventory (KPSI) to self-regulate learning, considering the participants’ knowledge before and after experiencing the sequence about specific ideas and procedures, through Likert scale responses (from 1 to 5 points). The instrument includes two parts. The first part is designed to evaluate the participants’ self-perception of what they have learned about the basic contents of the sequence, expressing in each of them what they knew before and after using an ordinal scale of 1 to 5, which refers to the following: 1: I do not know anything, 2: I know a little, 3: I know it well, 4: I know it very well, 5: I can explain it to a friend. The second part is intended to examine the emotions experienced in the activities of the sequence related to each of the basic contents, indicating which emotions they have felt among the nine that are presented; PSTs are also asked to explain what they have been based on to point out those emotions.

As Melo, Cañada, and Mellado (2017) explained, the causes of both, positive and negative emotions are mostly related to the subject matter knowledge. Furthermore, as we intended to make PST aware of the experienced activities (inquiry-based) because this is one of our learning objectives, apart from making them aware of the emotions they feel at each moment or activity developed throughout teaching sequence. For this reason, we decided to deepen the emotions they experienced at each specific moment, using self-reports methods described by Bellocchi (2015) to identify or recognize emotions in the inquiry. Bellocchi often used emotion labels from enthusiastic to bored (Ritchie et al. 2016) but for our study, we found the need to select different ones that offer a greater diversity in the kinds of emotions.

**Instrument validation and analysis**

In order to validate the content of the instrument, we considered the identification of the basic contents and the set of emotions that were presented. Regarding the basic content, an iterative process of review of the activities that make up the sequence by four researchers has been carried out, until a total consensus was found both in the content and in the writing of the items. The result is a set of eleven items that responds to four different categories, three on the approach of teaching by inquiry and modelling (expressing ideas, using models, obtaining evidence) and a final set on didactic reflection, as shown in Table 2.

<table>
<thead>
<tr>
<th>Table 2. Description of the sequence.</th>
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</thead>
<tbody>
<tr>
<td>Expression of ideas</td>
</tr>
<tr>
<td>Item 1. Express initial hypotheses: Why do you put salt on the roads when it snows?</td>
</tr>
<tr>
<td>Item 5. Represent hypotheses graphically and interpret</td>
</tr>
<tr>
<td>Use of models</td>
</tr>
<tr>
<td>Item 2. Justify hypothesis</td>
</tr>
<tr>
<td>Item 3. Molecular kinetic theory to explain changes in state</td>
</tr>
<tr>
<td>Item 8. Model to explain why the temperature drops when adding salt</td>
</tr>
<tr>
<td>Item 9. Make predictions for other similar phenomena</td>
</tr>
<tr>
<td>Look for evidence</td>
</tr>
<tr>
<td>Item 4. Design experiments to test hypothesis</td>
</tr>
<tr>
<td>Item 6. Data collection with the temperature sensor</td>
</tr>
<tr>
<td>Item 7. Analysis of data (coincidences and discrepancies with hypothesis)</td>
</tr>
<tr>
<td>Didactic reflection</td>
</tr>
<tr>
<td>Item 10. Teaching approach by inquiry and modelling</td>
</tr>
<tr>
<td>Item 11. What is science and how is it constructed?</td>
</tr>
</tbody>
</table>
The emotions considered were chosen using an adapted version of the Borrachero Cortés et al.’s (2015) model. We selected emotions, selecting only those more understandable and clearly different from the others, avoiding overlapping, and excluding those emotions that are not applicable to educational activities but to personal matters (e.g., love). Hence, we looked for the existence of the following kinds of emotions: Rejection, Concentration, Insecurity, Interest, Boredom, Confidence, Satisfaction, Dissatisfaction, and Shame. Our interest was not focused on stimulating some emotions and excluding others or to considering some emotions as positive (e.g., satisfaction, interest) and others as negative (e.g., boredom, insecurity), a dichotomy that has been used for the analysis of teaching practice (Marks 2000) by associating positive emotions to success and challenges and negative ones to failures and defections (Pekrun and Linnenbrink-Garcia 2014, cited by Bellocchi 2015). This is a dichotomous judgment that we do not adopt because we maintain that emotions are not always either positive or negative; instead, they are much more complex and take place in a continuum. Our interest focuses mainly on the first step of the model: the recognition of the emotions experienced, through an individual and collective reflection aimed at describing what kinds of emotions are experienced in the classroom context when a sequence of activities is implemented (Bellocchi 2015).

The reliability of the instrument associated with this sample of participants, that is, the reliability of the results, has been studied, in accordance with the recommendations of the Wilkinson (1999). Considering that the data referring to what they have learned before and after corresponding to a polytomous scale, the Cronbach alpha coefficient has been calculated using SPSS v.25. The value of this coefficient, considering the complete set of items referring to ‘what they have learned’ is 0.94, which indicates a high internal consistency but with redundancy in the items. However, the coefficient is calculated considering the items of each category we obtain the following values: expression of ideas 0.84, use of models 0.88, look for evidence 0.76 and didactic reflection 0.82. These values, between 0.7 and 0.9, show an acceptable internal consistency of the items referred to each category.

If we focus on data processing for the first part of the instrument, referring to their self-perception of what they have learned, although an ordinal scale of 1 to 5 has been used, we will treat it as a discrete quantitative scale in order to show global results by calculating the average and the statistical deviation. However, in order to perform statistical analysis to study the differences between what the participants reported that they knew before and what they knew afterwards, it must be considered that it is an ordinal variable and that the sample size is 24, these factors lead us to perform a nonparametric study and use the Wilcoxon test. As it is a single post-test, although it refers to the perception of what someone knows before and after engaging in the sequence, it is not appropriate to calculate the effect size.

**Role of researchers**

The first author took the lead in designing the instructional activities and served as the instructor of the course. The first author also took the lead in the design of the research study and the instruments used for data collection. To avoid a possible teacher-researcher bias, the other authors were responsible for the data collection and analysis.
Following on that, all authors engaged in the interpretations of the analysis and the production of the manuscript.

Findings and discussion

Which aspects of the sequence were perceived by the participants as the most influential on their learning?

The average of the responses provided by the participants of the questionnaire KPSI (‘how much’ they knew before and after experiencing the teaching sequence) for each of the procedural and conceptual contents studied is presented in Figure 1 graphically. The Wilcoxon test shows that there are significant differences between all pairs of items before and after, with a level of significance less than 0.001.

The ‘progress’ shows that all the values have increased. These data have been represented, by using different colours for the PSTs’ perceptions on their knowledge before and after experiencing the sequence. The pre- and post-sequence responses.

As shown in Figure 2, all changes show an increase in what the PST believes they know, starting by values greater than 1 (red), indicating that the effects of the teaching sequence are recognized by the participants in relation to knowledge acquired, both

<table>
<thead>
<tr>
<th>Items</th>
<th>Before</th>
<th>After</th>
<th>Evolution</th>
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<tbody>
<tr>
<td><strong>Expression</strong></td>
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<td></td>
<td></td>
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<tr>
<td>1</td>
<td>2,63</td>
<td>3,96</td>
<td>1,33</td>
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<tr>
<td>5</td>
<td>2,54</td>
<td>3,92</td>
<td>1,38</td>
</tr>
<tr>
<td><strong>Models</strong></td>
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<td></td>
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<tr>
<td>2</td>
<td>2,38</td>
<td>3,79</td>
<td>1,41</td>
</tr>
<tr>
<td>3</td>
<td>2,04</td>
<td>3,46</td>
<td>1,42</td>
</tr>
<tr>
<td>8</td>
<td>1,88</td>
<td>3,75</td>
<td>1,87</td>
</tr>
<tr>
<td>9</td>
<td>2,08</td>
<td>3,63</td>
<td>1,55</td>
</tr>
<tr>
<td><strong>Evidence</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>4</td>
<td>2,42</td>
<td>4</td>
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<td>5</td>
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<td>7</td>
<td>2,71</td>
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<tr>
<td><strong>Reflection</strong></td>
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<tr>
<td>10</td>
<td>2,13</td>
<td>3,79</td>
<td>1,66</td>
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<tr>
<td>11</td>
<td>2,79</td>
<td>4,17</td>
<td>1,38</td>
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</table>

Figure 1. Average of the responses provided by the participants for each category (showed in Table 1) of the questionnaire KPSI (‘how much’ they knew before and after experiencing the teaching sequence).
conceptual and procedural. The increase of the average on procedural content (hypotheses, design, graphics, data and analysis) indicates that they also recognise that they have learned to ‘do science’.

The two most remarkable changes correspond, on the one hand, to the item referring to the use of molecular kinetic theory to justify hypotheses, and on the other, to the item referring to the use of a model to explain the surprising data obtained on temperature drop when adding salt to the ice. If we consider the groupings made of the items, it is the category ‘use of models’ that shows the most change. In this case, initially preservice teachers express that they knew less, and it is the category in which the differences between the before and the after are superior. These results seem to indicate that the participants recognize that they have learned more than only the molecular kinetic theory to explain the phase changes as can be seen in the evolution on different items’ responses: Item 8. Model to explain why the temperature drops when adding salt showed a progression of 1.87, from 1.88 to 3.75 (which means ‘I know it very well’); or the Item 9. Make predictions for other similar phenomena shows a progression of 1.55 points. These results provide evidence that the participants perceived their engagement in scientific practices as beneficial while they also recognize how their learning was enhanced.

**What kinds of emotions did the participants experience?**

In Figure 3, both the emotions felt by the participants and their frequencies of each one are shown.

In general, it can be observed that the percentage of students who stated they had felt positive emotions (bluish colour) is higher than the percentage (less than 10%) who stated had they had felt negative emotions (reddish colour), which even don’t appear in
the last column (*Epistemology*: I know how scientific activity works and how scientific knowledge is constructed). We can also notice that several emotions are more remarkable than others because of the high percentages obtained; this is the case of *Interest, Confidence, Concentration, Satisfaction*, and *Insecurity*.

In the case of negative emotions, the most commonly experienced one is *Insecurity*, felt in every activity when we refer to the learning of *epistemology*. If we focus a bit on this emotion, we can see that when PST report having felt *insecurity* it is basically in *hypothesis, justification, theory, graphics, analysis* and *prediction*. However, it appears in a smaller number of participants (only two) when referring to the *design, data, model, inquiry* and *epistemology*. If we analyse in Figure 3 temporal moments throughout the teaching sequence we find that, at the beginning, seven participants experienced *insecurity* and, as the sequence progress, fewer student-teachers indicate feeling it, which seems to show that as the sequence makes sense for them, it makes them feel *confidence* and *satisfaction* (the emotions which in fact increase). Therefore, we assert that the participants recognized the existence of *insecurity* and *dissatisfaction* with their own ideas. However, when considering that they were developing new understandings during that time, this does not seem to be negative. With instruments designed, we link what they have learned with the emotions felt, making them aware of positive emotions like *satisfaction* or *interest* experienced when they ‘doing scientific practices’.

**Participants’ views about the importance of using models in the context of scientific practices changed**

The results about the participants’ views about practical laboratory work (from the questionnaire used by Pino Álvarez et al. 2012) are represented in Figure 4, gathering the answers from 1 to 3 as ‘Very Important’, 4 to 6 as ‘Important’ and 7 to 9 as ‘Unimportant’. The double column corresponds to the results of the pre-test (before
implementing the teaching sequence) and post-test (after implementing the teaching sequence).

Apart from the answers about everyday phenomena that remained unchanged at levels of maximum importance (50%), all aspects seem to diminish in importance in favour of the use of models, which has received high importance. We calculated the statistical significance of the couple of pre- and post-data values for ‘Very Important’, obtaining statistical significance in columns for Using Models. This can be considered as further evidence about the effectiveness of the teaching sequence in supporting the participants’ views about the usefulness of scientific practices as an alternative approach to teaching.

Conclusions and implications

In response to recommendations about the need to engage preservice teachers in scientific practices and the lack of the enactment of such practices in science classrooms, in the study reported in this paper, we explored the use of scientific practices with special emphasis on model-based inquiry in the training of secondary school teachers. The teaching sequence presented in these manuscript, places preservice teachers as learners (i.e., they experience learning of scientific content through scientific practices) and as thinkers (i.e., they reflect on the process experienced, the conceptual and procedural contents learned and the emotions felt in each activity) emphasizing the integration of scientific practices into lesson planning and teaching (Saribas and Ceyhan 2015). Hence, one contribution of this study is that it adds to the limited existing knowledge base on scientific practices by offering a concrete example of the design and implementation of a teaching sequence in the context of secondary science teacher education.

Through the analysis of the components of the sequence, we addressed the challenge that the training received by most prospective teachers has done little to support
them in developing an explicit knowledge of scientific practice and associated procedural and epistemic knowledge. In addition, we addressed relevant aspects of teachers’ knowledge in a practical way as we engaged preservice teachers in learning to teach through a model which includes: Knowledge of potential of specific tasks for learning, their goals and purposes, their cognitive demands, their effective orchestration in the classroom, and the need to learn the procedural and epistemic features of science; importance of prior knowledge as a lens for interpreting, typical errors, and ways of assessing student knowledge and comprehension; knowledge of explanations for some of the ideas of science, their inherent complexity, and ways of illuminating the disciplinary nature of science.

A secondary goal of the study was to evaluate the effect of the teaching sequence on preservice teachers’ perceptions of their knowledge development (conceptual knowledge and scientific practices domain), the emotions they experienced in each inquiry-based activity and to what extent the recognition of the advantages of the scientific practices as the potential to learn models and theoretical contents. The analysis of the data showed that overall there has been a great progress in the knowledge that the participants perceived to have developed on each conceptual and procedural content addressed. In particular, the two items related to the utility of models and theory to justify hypotheses, added to the different purposes/advantages of the scientific practices that participants identify to experiment a high enhancement. Other relevant results include the evolution in the main purposes/advantages of making scientific practices that the participants consider before and after implementing the sequence, since they are considered the main purpose of scientific practices their students motivation (item most voted in the pre-test, 50%) to consider more important the fact of these practices promote to explain phenomena (50% in the post) and the use of models (considered only by 3% of the participants in the pre-test and selected by ~45% in the post).

If we combine the results of both analyses, we can conclude that the participants have not only become aware of learning science (both conceptual and procedural contents), but they have also become conscious of the connection between theory-practice that the implementation of scientific practices nurtures. As exemplified in another study (Jiménez-Liso et al. forthcoming), one of the reasons for the lack of presence of scientific practices in science classrooms seems to be that the potential of these practices to connecting theory-practice goes unnoticed for teachers, considering only the motivation that scientific practices generate on their students. This often leads teachers to discard the incorporation of scientific practices in their science teaching due to the investment of time and effort they require and the high curricular pressure they have to target. Hence, these results combined are important because they reveal that the participants perceived that scientific practices are quite useful for supporting science learning that goes well beyond student motivation. As the results showed, the participants recognized and emphasized scientific learning as modelling and they also stated that they intend to implement scientific practices as future teachers.

This, however, would not have been possible if the teaching sequence had left the participants feeling indifferent. As evident in the findings, the participants exhibited positive emotions about both their engagement in scientific practices as well as their understandings of the several benefits of the use of scientific practices in teaching. As illustrated in existing literature, both positive and negative emotions play an important role in teachers’
construction of pedagogical content knowledge, curriculum planning, and relationships with children and colleagues (Brígido et al. 2010; Schutz and Pekrun 2011). We hence argue that there is a need to expand current conceptions of knowledge and acknowledge the role of emotional knowledge, given the interrelation between pedagogical content knowledge and emotions (Zembylas 2007).

Similar findings pointing to the strong link between emotions experienced throughout engagement with science and academic achievement were revealed in a multilevel modelling study, carried out by Grabau and Ma (2017) who found that all nine aspects (i.e., science self-efficacy, science self-concept, enjoyment of science, general interest in learning science, instrumental motivation for science, future-oriented science motivation, general value of science, personal value of science, and science-related activities) of science engagement were statistically significantly and positively related to science achievement. Based on these findings, the researchers recommended two science teaching practices as key mechanisms for enhancing science engagement: science teaching with a focus on applications or models and with a focus on hands-on activities (Grabau and Ma 2017).

In the context of the course that defined the context of this study, we paid special attention and provided preservice teachers with opportunities to become aware of their emotions as learners and as future teachers, as they engaged in scientific practices. Essentially, our goal was to support preservice teachers to not only ‘speak science’ and ‘do science’ but also to ‘feel science’ for the purpose of addressing goals related to emotions, aesthetics, and well-being in science education (Bellocci, Quigley, and Otrel-Cass 2017). We did that by offering opportunities for teachers to personally relate to the daily phenomenon under exploration, to work with others assuming that multiple kinds of emotions are experienced through collaboration, to reflect on their emotions during their engagement in the instructional sequence, and to engage in discussions about their well-being as preservice teachers.

The findings of our study contribute to the knowledge base of emotions in science education as they illustrate the importance of providing preservice teachers with opportunities to explore their emotions especially in relation to self-regulation when engaging in teaching sequences in teacher preparation. However, further research is recommended that exemplifies the nature of preservice teachers’ emotional engagement and emotional trajectories aligned with scientific practices within diverse geographical and sociocultural contexts for the purpose of addressing cultural aspects of affective domains of learning.

**Disclosure statement**

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