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# Assessing Science Teaching Explanations in Initial Teacher Education: How Is This Teaching Practice Transferred Across Different Chemistry Topics?

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**Abstract**

One of the core practices of science teachers is the construction of science teaching explanations. These explanations serve to clarify concepts, procedures, facts, ideas, or types of problems, and are aimed at promoting student understanding. The low performance of Chilean science teachers on explanations has led us to incorporate instances in chemistry teachers education specifically aimed at developing the necessary skills to construct subject-adequate science teaching explanations. The objective of this research was to characterize the transference of the components of preservice teachers' subject-adequate science teaching explanations across different chemistry topics. Through a qualitative methodology with an exploratory case study approach, we analyzed a total of 112 scientific explanations constructed by 28 chemistry preservice teachers throughout a 4-month training process. Our results show that, for the analyzed sample, the formulation of subject-adequate science teaching explanations involve different components whose development has distinctive characteristics. The criteria associated with the form of the explanations, which depend on teachers' discursive knowledge, can be developed in teachers' education through recursive strategies for the formulation of science teaching explanations across different chemistry topics. The criteria associated with the function of the explanations, which depend on teachers' content knowledge, require other strategies besides the disciplinary courses and recursive strategies for the formulation of science teaching explanations, to get teachers to formulate subject-adequate science teaching explanations across different chemistry topics. The work developed can provide instructional and evaluative strategies for science teachers' education, oriented to one of the teaching core practices that requires our attention as teacher trainers.

**Keywords** Preservice teachers · Teacher training · Explanation · Teaching practice · Chemistry

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## Introduction

In recent years, there has been intense debate seeking to identify core teaching practices that allow science teachers to effectively guide the learning processes of students (Reiser 2013). As science instruction typically involves the teacher explaining science ideas (along with a range of other learning experiences) (Geelan 2012; Trygstad 2013), explaining has been identified as one of the core teaching practices of science teachers (Windschitl et al. 2012; Zangori and Forbes 2013).

Several investigations have evaluated the quality of teachers' explanations in science lessons. Most of those studies found that the explanations offered were poor in quality and included logical flaws and errors of scientific facts (Goodwin 1995; Leite et al. 2007; Zangori and Forbes 2013). In Chile, where the present study was conducted, the Ministry of Education has identified important weaknesses in science teachers' explanations (Government of Chile 2013). It is therefore crucial to improve the quality of the explanations provided by teachers so that students can more effectively and efficiently develop scientific knowledge (Geelan 2012).

Given that the construction of teachers' explanations is mediated by many factors (Helmke 2006), it is reasonable to assume that the quality of teachers' explanations varies and is subject to multiple personal and contextual factors (Kulgemeyer and Riese 2018). We are particularly interested in exploring the case of chemistry teachers undergoing initial teacher education. Little is known about the quality of explanations that chemistry preservice teachers construct after receiving instruction in chemistry or chemistry education (Talanquer 2010). This knowledge is of central importance if we want to evaluate the extent to which these courses help chemistry teachers develop the capacity to construct scientifically and pedagogically appropriate explanations.

The present study, therefore, focuses on characterizing the ways in which preservice teachers develop their explanatory capacity within their initial training as science teachers, and how capable they are of putting into action this teaching practice in the various topics of the school curriculum of chemistry.

## Towards Subject-Adequate Science Teacher Explanations Within Teacher Education

### Scientific Explanations and Science Teaching Explanations

Scientific explanations are communicative actions intended to make sense of phenomena and make them understandable (Thagard 1992). In a teaching context, scientific explanations have philosophical and epistemological differences from science teaching explanations (Treagust and Harrison 1999). Science explanations and science teaching explanations differ in rigor, length, and detail, and tend to have different degrees of openness. Scientific explanations are evidence-driven statements, law-like, highly generalized, and rigidly logical. Their purpose is to share an understanding of a phenomenon with scientific communities (Cabello and Topping 2018). On the other hand, science teaching explanations are more open and fluid and draw on analogies, metaphors, examples, axioms, and concepts that connect with students' prior understandings and life contexts (Geelan 2012). Their purpose is to lead students to construct meaning, and science teaching explanations can be collaboratively shaped (Dawes 2004) to promote learning through the interactions that occur during their collective construction.

Science teaching explanations require teachers to construct knowledge not only about science and scientific explanations but also about curriculum and learning processes, and to be reflective and adaptative to students' ideas during instruction (Otero and Nathan 2008; Zangori and Forbes 2013).

## Characterizing Science Teaching Explanations

Previous studies have characterized science teaching explanation, progressively analyzing this teaching practice based on Lemke's social semiotics (Lemke 1998). These studies have allowed us to define a model of explanation for subject-adequate and addressee-oriented science teaching explanations (Kulgemeyer and Tomczyszyn 2015).

Reviewing the literature associated with the characterization of scientific explanations in the school context, Yeo and Gilbert identified three facets of teachers and students' scientific explanations: (1) function, (2) form, and (3) level (Yeo and Gilbert 2014). The *function* of explanations has been characterized according to the question to which they respond, from non-causal to causal levels (Gilbert et al. 2000). The *form* of the explanations refers to the characteristics of the discourse, which is approached from the perspective of functional linguistics to identify its organizational structure (Unsworth 1998). Finally, the *level* of explanations refers to its precision, abstraction, and complexity, characterizing the adequacy of the reasoning according to the audience of the explanation (Yeo and Gilbert 2014).

Cabello and Topping (2018) proposed a set of evidence-based categories that allow science teachers' explanations to be exhaustively characterized. According to the authors, science teaching explanations can be evaluated in terms of their (a) clarity, (b) coherence and cohesion, (c) sequence, (d) correctness, (e) completeness, (f) connection with learners' knowledge, (g) metaphor, analogy, simulation or model usage, (h) example, experiment, graph or image usage, (i) gestures and speech usage, and (j) the recognition and used of misconceptions as learning opportunities. Once this group of categories had been validated as components of a science teaching explanation, the authors distinguished three levels of performance (low, intermediate, and high) on each of these components. This has allowed the construction of an analytical tool for teaching science explanations that identifies the level of performance in each of the components, and in turn defines what features an explanation should have to be considered a high-leverage science teaching explanation (Cabello and Topping 2018).

Explanations are judged to be subject-adequate (or not) according to the clarity with which they outline the entities perceived to be involved in a phenomenon, their relationships or processes and the related circumstances producing the phenomenon (Kulgemeyer and Tomczyszyn 2015). Such judgments can be used to inform the analysis of the *function* of the explanation (Gilbert et al. 2000). As explanations are associated with phenomena framed in different scientific topics, teachers' capacity to construct accurate and complete explanations with an appropriate sequence (Cabello and Topping 2018) is strongly associated with a deep understanding of the subject matter (Sevian and Gonsalves 2008). On the other hand, the *form* of the explanation provides the overall organizational structure of a science teaching explanation and allows identification of the language features of this genre. This usually implies, for teachers and students, struggling with multiple complex structures and specific terms (Perkins and Grotzer 2005; Unsworth 1998) to construct clear, coherent, and cohesive explanations (Cabello and Topping 2018). Thus, the formulation of subject-adequate explanations requires both *content knowledge* and *discourse knowledge* (Lachner and Neuburg 2019).

The information communicated through science teaching explanations is provided by a combination of different signs such as oral or written speech, models, graphs, images, or gestures (Cabello and Topping 2018). These signs can be used to inform the level of precision, abstraction, and complexity of the explanation produced, which is related to the *level* of the explanation (Yeo and Gilbert 2014). Kulgemeyer and Tomczyszyn (2015) consider that teachers' explanations are addressee-oriented when their *level* is appropriate to the students to whom the explanation is communicated. Thus, the formulation of addressee-oriented explanations requires *pedagogical content knowledge* (Lachner and Neuburg 2019).

The complexity of these criteria, expected to be met by science teaching explanations, shows how challenging it can be for teachers to build explanations that can effectively contribute to students' understanding in science classes (Ball and Forzani 2011).

## Learning to Construct Science Teacher Explanations Within Initial Teacher Education

Preservice teachers require extensive opportunities to connect content knowledge, discursive knowledge, and pedagogical content knowledge on their own (Avraamidou and Zembal-Saul 2010), before they face the multiple challenges of real school settings. Hence, Cabello and Topping recommend gradually introducing preservice teachers to real settings of practice to allow them to orchestrate the knowledge and skills needed for teaching (Cabello and Topping 2018). They suggest that the skills of making scientific ideas explicit for teaching can be developed during initial teacher education, if targeted practices are analyzed and rehearsed in protected formative contexts. Teaching practice in simulated settings might be introduced in the early stages of teacher education, focusing on the construction of subject-adequate science teaching explanations (Cabello and Topping 2018). Later, as preservice teachers approach diverse groups of students with different needs, they can incorporate the components that allow them to construct addressee-oriented—as well as subject-adequate—science teaching explanations. Thus, the construction of subject-adequate science teaching explanations is identified as a first milestone to be achieved during initial teacher education.

Building on the work of Cabello and Topping (2014, 2018), we scaffolded preservice teachers and gave them opportunities to build subject-adequate written explanations of phenomena, understandable for high school students. Formulating explanations for "fictitious others" has been reported in the literature as a constructive learning activity, since preservice teachers need to adapt their explanations to the needs of these fictitious others and transform their knowledge in such a way that the information provided is tangible to the addressees (Lachner and Neuburg 2019). Written explanations were also constructed because, although there are reports in the literature of the low effect of the construction of written explanations on student learning (Bangert-Drowns et al. 2004), these authors also state that the effect could be greater if students are supported in the implementation of the rhetorical characteristics that contribute to the comprehensibility of their explanations (Lachner and Neuburg 2019). In fact, several studies revealed promising gains as a result of writing-to-learn, when it is grounded in the following theoretically informed activities and contexts: (1) opportunities for brainstorming, (2) provision of authentic audiences, (3) drafting and redrafting with feedback, (4) explicit instruction in genre specifications, (5) focus on big ideas, (6) use of rubrics, and (7) diverse opportunities to plan and draft writing (Gere et al. 2019; Gunel et al. 2007; Klein 1999, 2015).

Given that a chemistry teacher must address various topics throughout the curriculum, the ability to transfer teaching practices across various topics has been identified as challenging for preservice teachers (Lachner and Neuburg 2019). These authors have studied the ability of preservice teachers to transfer their explanatory abilities between different topics in terms of their cohesion, finding that when students received feedback on their conceptual maps, their performance was improved in solving challenging transfer tasks (Lachner and Neuburg 2019). Further research is required, however, to explore the transferability of other components of science teaching explanations, and how teacher training programs could better support preservice teachers to transfer their explanatory capacity.

### Research Question

The low performance of science teachers in the construction of science teaching explanations, together with the absence of research literature on how science teachers develop and transfer their explanatory capacity, supports the value of paying more attention to the development of this core teaching practice. A better understanding of how preservice teachers learn to build science teaching explanations could orient the science teachers initial education programs to helping beginning teachers formulate subject-adequate science teaching explanations across different chemistry topics.

Thus, the question that guides this research is:

> How are the components of subject-adequate science teaching explanations of preservice teachers transferred across different chemistry topics?

## Methodological Framework

Because our objective is to characterize the transference of the components of preservice teachers' subject-adequate science teaching explanations across different chemistry topics, we are positioned within a qualitative research paradigm with a case study approach (Yin 2003). This is an exploratory case study, as it facilitates the exploration of the phenomenon within its context, in order to reach concrete and particular abstractions pertinent to the analyzed sample and from which patterns can be identified (Baxter and Jack 2008). Our cases are chemistry preservice teachers and our units of analysis are the science teaching explanations constructed within their initial teacher education.

### Context and Participants

This study was conducted within a secondary education chemistry teacher education program at a Chilean university. This four-year program includes both disciplinary content knowledge courses and pedagogical courses, and later the integration of these domains through five courses with contents focused on pedagogical content knowledge (PCK), as well as on pedagogical practices. These PCK courses, beginning in the third year, constitute a sequence that progressively scaffolds the integration of disciplinary and pedagogical knowledge addressed in previous courses.

The PCK courses follow a progressive approach to teaching practices, from simulated scenarios in which simple problems are posed to real scenarios, as can be seen in Fig. 1 (Li 2019). This strategy aims to move towards new and increasingly complex understandings of the knowledge required to teach (Ball & Forzani 2009; Shulman 1987).

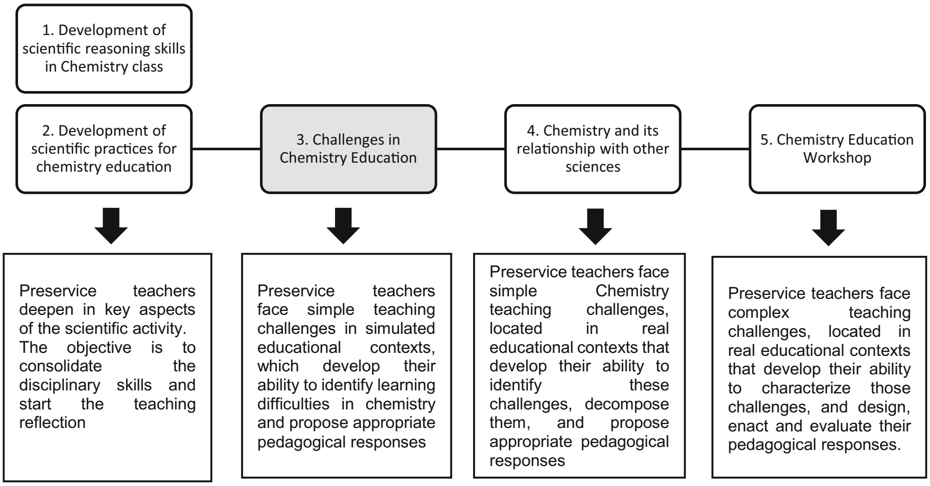


**Fig. 1** Sequence of PCK courses in the secondary education chemistry teacher education program

Our study was developed within the third PCK course (Fig. 1) in the program, called *Challenges in Chemistry Teaching.* Preservice teachers have constructed disciplinary knowledge in Chemistry through the theoretical and experimental courses undertaken during the first 2 years of teacher education but have had few opportunities to formulate scientific explanations. This 4-month course constitutes an instance in which they are expected to formulate subject-adequate science teaching explanations (Kulgemeyer and Tomczyszyn 2015).

Two academics participated in this course in a co-teaching modality: one specializing in chemistry and the other specializing in chemistry education. These teachers are also researchers in chemistry education, and two of the four authors of this paper.

## Data Collection

The design of the activities developed in this course focus on the construction of subject-adequate science teaching explanations involved the selection of phenomena to be explained, shown in Table 1. Since we wanted to explore the transferability of the components of science teaching explanations, the selected phenomena are located in various chemistry topics. Chemistry is the science that studies the composition, structure, and properties of matter and the chemical reactions by which one substance becomes another (Spencer et al. 2006, p.2), so we have made sure to select phenomena that require identifying the chemical species involved and characterizing chemical reactions stoichiometrically and thermodynamically.

In Fig. 2, we present the implemented strategy, following theoretical considerations for writing-to-learn activities reported in the literature (Lachner and Neuburg 2019).

In the past 5 years, of the nearly 50 preservice teachers who have completed the degree program, 28 have participated in all instances of formulation of science teaching explanations. Those 28 preservice teachers, then, constitute the convenience sample of our study. It consisted of 20 women and 8 men, aged between 21 and 25 years. All of them were informed of the research project and agreed that their written productions could be analyzed as data for this research work.

The collected data correspond to preservice teachers work (e.g., written accounts) in which they sought to develop subject-adequate science teaching explanations for chemical

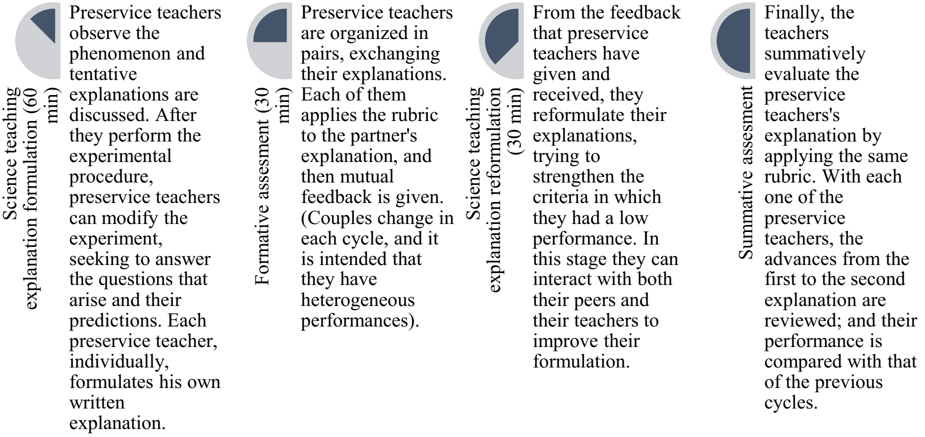
**Table 1** Chosen phenomena for the construction of subject-adequate science teaching explanations

| | Activity | Phenomena | Question that favors the explanation |
|---|---|---|---|
| E1 | Heating sugar | Sucrose combustion | Why does a color change occur in sugar when it is heated in a spoon? |
| E2 | Snowing in a glass | Precipitation of NaCl from a saturated solution of NaCl by adding drops of absolute ethanol | Why does sodium chloride precipitate when drops of absolute ethanol are added to a saturated NaCl solution? |
| E3 | From one side to the other | Displacement of chemical equilibrium by the effect of temperature in blisters of $N_2O_4$ - $NO_2$ | Why does color change occur in a blister containing $N_2O_4$ - $NO_2$ at equilibrium, when submerged in hot water or in ice? |
| E4 | ¿Cold or hot? | a) Hydration of anhydrous calcium chloride | Why does adding water to anhydrous calcium chloride produce heating of the test tube? |
| | | b) Dissolution of ammonium nitrate in water | Why does adding water to ammonium nitrate produce cooling of the test tube? |

phenomena observed in class according to the recursive formulation strategy. Each created four drafts of each explanation. As such, there are a total of 112 examples of preservice teachers' written work that together make up the collected data for this study.

## Data Analysis

The analysis of the science teaching explanations was done by applying a category system, referred to as the components of science teaching explanations, adapted from Cabello and Topping (2014, 2018). We have selected this analytical tool because it was constructed from empirical evidence of science preservice teachers' explanations. In addition, we consider that it is the most appropriate because it identifies in more detail the criteria that science teaching explanations are expected to meet and proposes performance levels that allow us to characterize the explanations of our students in greater detail. The instrument, presented in Table 2, functions both as a rubric to evaluate the science teaching explanations in the course and as an instrument of analysis for this research.



Science teaching explanation formulation (60 min)

Preservice teachers observe the phenomenon and tentative explanations are discussed. After they perform the experimental procedure, preservice teachers can modify the experiment, seeking to answer the questions that arise and their predictions. Each preservice teacher, individually, formulates his own written explanation.

Formative assesment (30 min)

Preservice teachers are organized in pairs, exchanging their explanations. Each of them applies the rubric to the partner's explanation, and then mutual feedback is given. (Couples change in each cycle, and it is intended that they have heterogeneous performances).

Science teaching explanation reformulation (30 min)

From the feedback that preservice teachers have given and received, they reformulate their explanations, trying to strengthen the criteria in which they had a low performance. In this stage they can interact with both their peers and their teachers to improve their formulation.

Summative assesment

Finally, the teachers summatively evaluate the preservice teachers's explanation by applying the same rubric. With each one of the preservice teachers, the advances from the first to the second explanation are reviewed; and their performance is compared with that of the previous cycles.

**Fig. 2** Strategy to favor the recursive formulation of science teaching explanations

**Table 2** Categories to analyze subject-adequate science teaching explanations (adapted from Cabello and Topping 2018)

| Facets of science teaching explanations (Yeo and Gilbert 2014) | Criteria (Cabello and Topping 2018) | | Level 1 (low performance) | Level 2 (intermediate performance) | Level 3 (high performance) |
|---|---|---|---|---|---|
| Function | Sequence | The explanation has an organizer principle. Every part of the explanation should be deducible from the precursor condition. | Ideas are presented in a disorganized way, do not follow a logical order that facilitates understanding. | Some ideas are presented in a disorganized way, breaking the logical order of the explanation. | The ideas are presented in an organized manner following a logical order that facilitates the understanding of the explanation. |
| | Accuracy | Precision in the use of terms regarding current scientific concepts, theories, or principles. | References to scientific models and theories are erroneous and contain conceptual inaccuracies. | Some erroneous theoretical referents or conceptual inaccuracies appear. | The theoretical referents that appear are precise and are presented in a precise and adequate way to the expected level. |
| | Completeness | The components of the explanation are sufficient for understanding. | The reasons or arguments developed do not refer to the object or phenomenon of the explanation or are not relevant to understand it. | Some reasons or arguments presented do not refer to the phenomenon or are not relevant to understand it.<br>The reasons presented are not sufficient to understand the phenomenon. | The reasons or arguments refer to the phenomenon and are relevant and sufficient to understand it. |
| Form | Clarity | Features, patterns, and structure of the content are illustrative and focused. | The explanation is difficult to understand because several inferences are necessary, or because inadequate or very complex vocabulary is used. | Some parts of the explanation are difficult to understand because there are elements that the learner should infer, or inadequate or complex vocabulary is used. | The explanation is understandable because all the relevant elements appear, and the language is adequate and with an appropriate level of complexity. |
| | Coherence and cohesion | Coherence is about how the bits of the explanation are linked together to make sense, and cohesion implies connective links between the parts that internally relate clauses and sentences. | The ideas presented are not explicitly and causally connected (descriptive). | Some of the ideas presented are disconnected from the main ideas (or their connection is not explicit) or the connections are not causal. | All the ideas presented are explicitly and causally connected. |

We present the analysis of one explanation that is part of the sample, as an example.

### Activity: Snowing in a Glass

The phenomenon of *Snowing in a glass* refers to the precipitation of sodium chloride by adding absolute ethanol to a saturated solution of sodium chloride at room temperature. An expected explanation of this phenomenon would be the following in Fig. 3.

Thus, in the explanation, it is expected that preservice teachers identify the competition between the intermolecular forces of water, ethanol, and sodium chloride as the cause of the phenomenon observed. The explanation of one of the preservice teachers in the sample (S24) is transcribed below, and the process of analysis shown.

The explanation begins with an initial statement, in which the phenomenon is described. Next, the intermolecular forces between water and ethanol are discussed, identifying the formation of hydrogen bonds, and the solvation of the salt, without specifying the type of forces between salt and water. When mixing the two solutions, the explanation refers to the interactions between the hydrogen and oxygen atoms of ethanol and water, citing as a cause, in addition to its affinity, the decrease in the ionic strength of the solution by the precipitation of the salt. However, later it is suggested that these interactions compress the system, and that this causes the salt, by its size, to precipitate.

For each criterion, we identified the level of performance by applying the categories shown in Table 3. In Table 4, we present the categorization of the five criteria, justifying, based on the preservice teachers' explanation, her level of performance.

To ensure the reliability of the data analysis, the first set of data was analyzed by several investigators independently. This allowed us to refine the descriptors for each of the categories, achieving a greater degree of agreement in the coding of the explanations of preservice teachers. Then all data were coded by two researchers independently. To determine the level of affinity between the experts' evaluations, Cohen's kappa index was employed (Cerda and Villarroel 2008). The strength of the agreement in categorizing preservice teachers' written explanations was 0.81. Those results are considered substantial in terms of their validity (Landis & Koch 1977).

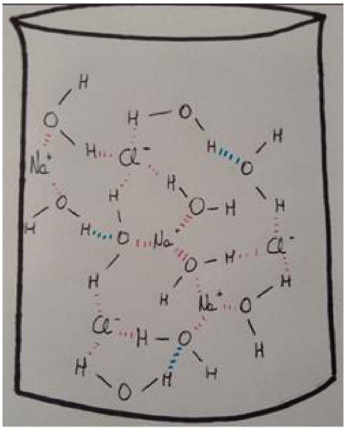
## Main Findings

We applied the analysis strategy to the 112 preservice teachers' explanations formulated within the course (E1, E2, E3, and E4, shown in Table 2). We categorized the preservice teachers' performance in each of the five criteria, identifying whether they had exhibited low (L1), intermediate (L2), or high performance (L3) (Cabello and Topping 2018).

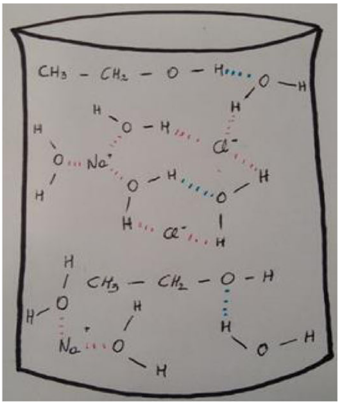
### Individual Transference of the Components of Subject-Adequate Science Teaching Explanations of Preservice Teachers Across Different Chemistry Topics

Below, we present the results of the analysis of one of the explanations given by one of the preservice teachers in the sample. Excerpts of her explanations of the E2 and E4 phenomena are used as examples to show with greater clarity how preservice teachers' explanations progress during the course (Table 5).

**Fig. 3** Example of analysis of a preservice teacher science teaching explanation



**a)** Saturated sodium chloride solution (Source: E2 Preservice teacher's science teacher explanation S14)



**b)** Rearrangement of chemical species when adding absolute ethanol to a saturated sodium chloride solution (Source: E2 Preservice teacher's science teacher explanation S14)

**Table 3** E2 science teaching explanation (S24)

| Line | Explanation analyzed |
|---|---|
| 1 | By adding absolute ethanol to a brine, water and sodium chloride, it is observed that the salt |
| 2 | begins to precipitate, generating the impression of falling snow. |
| 3 | This phenomenon is explained by the generation of molecular interactions of the hydrogen bond type |
| 4 | between ethanol and water. The salt is solvated by water, dissociating the ions that make |
| 5 | up the crystal lattice; When adding a volume of ethanol, the water and ethanol molecules begin |
| 6 | to interact by the affinity of the oxygen and hydrogen atoms with high partial load mainly, producing |
| 7 | that they increase the interactions between the ionic components of the salt, |
| 8 | decreasing the ionic strength of a dissolution, since the crystalline lattice that forms the salt re-forms |
| 9 | eliminating the concentration of dissociated ions. The interactions that generate water |
| 10 | and ethanol compress the system, producing that the salt being large does not find space in the |
| 11 | rearrangement of the solution, and having no component that solvates the salt, it precipitates. |

**Table 4** Example of analysis of S24 science teaching explanation of phenomenon E2

| Criteria | Analysis | Performance |
|---|---|---|
| Sequence | The explanation refers to the organization at the molecular level of the dissolution before [4–5] and after adding the ethanol [3–4, 5–11], without following a chronology of events, jumping between two or more situations, which hinders students' understanding | Ideas are presented in a disorganized way, do not follow a logical order that facilitates understanding. **(N1)** |
| Accuracy | Several inaccuracies appear in the text, such as the reference to the contraction of the sample [9] caused by the formation of hydrogen bonds, or identifying salt as a large chemical species [10], in relation to water and ethanol molecules. | References to scientific models and theories are erroneous and contain conceptual inaccuracies. **(N1)** |
| Completeness | While the concept of solvation is used [4], the explanation does not detail the intermolecular forces between water and salt (ion-dipole), nor compares them with hydrogen bonds between ethanol and water. Nor does it establish as relevant that the dissolution of water and salt is saturated, which justifies the competition between interactions [11–12]. | Some reasons or arguments presented do not refer to the phenomenon or are not relevant to understand it.<br>The reasons presented are not sufficient to understand the phenomenon. **(N2)** |
| Clarity | The explanation refers to the salt [4] and to a crystal lattice [5] without explicitly relating them. Understanding the explanation then requires the student to infer that these terms refer to the same chemical species. | The explanation is difficult to understand because several inferences are necessary, or because inadequate or very complex vocabulary is used. **(N1)** |
| Coherence and cohesion | The use of connectors in the explanation, some causal such as "since" [8] and "producing that" [10], gives an account of the intention to give coherence and cohesion to the text. However, no causal relationships are established between all the elements. The text also presents contradictions when identifying the appearance of hydrogen bonds between ethanol and water [3–4] as a cause and as a consequence, at the same time, of the precipitation of the salt. | Some of the ideas presented are disconnected from the main ideas (or their connection is not explicit) or the connections are not causal. **(N2)** |

**Table 5** Individual transference of the components of subject-adequate science teaching explanation (S26)

| | **E2 Science Teaching Explanation (S26)** ***Snowing in a glass*** | **E4 Science teaching Explanation (S26)** ***¿Cold or hot?*** | |
|---|---|---|---|
| **1** | […] When added to the mixture of | […] An exothermic reaction or process is | **1** |
| **2** | water and salt, the ethanol interacts with | a reaction where heat is released. This | **2** |
| **3** | the water by forming hydrogen bonds, | means that the energy of the molecules of | **3** |
| **4** | causing the water to stop interacting | the products is lower than the energy of | **4** |
| **5** | with the Cl$^-$ and Na$^+$ ions. When the | the molecules of the reactants. The above | **5** |
| **6** | water stops interacting with the ions, | can be explained by the hydration energy, | **6** |
| **7** | the forces that kept them together (ion- | this belongs to thermodynamic processes | **7** |
| **8** | dipole) are disadvantaged, given that | of solutions of ionic compounds. When | **8** |
| **9** | the interaction by hydrogen bound with | we find an aqueous solution, the ions are | **9** |
| **10** | ethanol gives greater stability to the | surrounded by polar water molecules. A | **10** |
| **11** | molecules, and in turn favors the ion- | primary hydration sphere of water | **11** |
| **12** | dipole interaction. In this way the | molecules surrounds the cations, with the | **12** |
| **13** | chloride and sodium ions that begin to | partially negative oxygen atoms oriented | **13** |
| **14** | be released, interact again between | towards the cation. Similarly, the anion is | **14** |
| **15** | them forming the precipitate, which | surrounded by water molecules with | **15** |
| **16** | corresponds to the organization of Na$^+$ | partially positive hydrogen atoms oriented | **16** |
| **17** | Cl$^-$ in solid NaCl, forming the crystal | towards the anion. The formation of | **17** |
| **18** | lattice interaction mentioned above. | dipole ion-type interactions in hydrated | **18** |
| **19** | […] | ions is very exothermic […] | **19** |

| **Criterion** | Performance | | Transference of the components |
|---|---|---|---|
| | E2 | E4 | |
| **Sequence** | L2 | L2 | While most of the ideas follow a logical order, in both explanations ideas that break the logical order of explanation remain [E2.10-11; E4.10-11]. |
| **Accuracy** | L3 | L1 | While explanation E2 did not contain conceptual inaccuracies, explanation E4 contains many inaccuracies [E4. 5-6; 17-18-19]. |
| **Completeness** | L2 | L1 | While in explanation E2 some arguments were missing to fully explain the phenomenon, in E4 the preservice teacher is not capable to identify which are the arguments that would allow her to explain the phenomenon. |
| **Clarity** | L2 | L3 | While the understanding of the E2 explanation requires making some inferences to be understood, the E4 explanation presents all the elements with an appropriate vocabulary [E4.8-9-10]. |
| **Coherence and cohesion** | L1 | L2 | In E2 there are hardly any connectors, and none is causal [E2. 11-12], it is more of a descriptive text. In E4 more connectors appear, and some are causal [E4. 5-6; 14]. However, the preservice teacher still cannot formulate a fully cohesive and coherent explanation. |

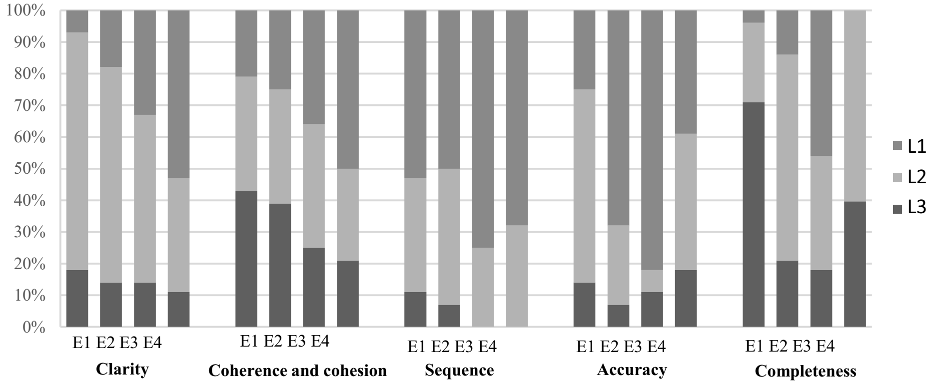


**Fig. 4** Preservice teachers' performance in each explanation

## Global Transference of the Components of Subject-Adequate Science Teaching Explanations by Preservice Teachers Across Different Chemistry Topics

We applied the same analytical strategy to the explanations of the 28 preservice teachers that constitute the cases of our research. This has allowed us to study, for all cases, how the components of their explanations were transferred.

We organized the preservice teachers' explanations according to those levels in Fig. 4. The percentage corresponds to the number of preservice teachers located at the three levels of performance, for each of the criteria analyzed (Table 3).

As can be seen in Fig. 4, some of the criteria analyzed show a progression during the course (clarity and coherence and cohesion), while others present variable trajectories (sequence, accuracy, and completeness). We have organized the results of our study in two sections in order to present them clearly: criteria on which performance improves consistently and criteria on which performance is variable.

A. Criteria on which performance improves consistently

The criterion of *clarity* refers to the adequacy of the language of the explanation (Cabello and Topping 2014). Initially, most of the preservice teachers (75%) are at an intermediate level of performance. As they develop their science teaching explanations, there is a progressive increase in the number of preservice teachers who achieve high performance, so that at the end of the course half of the preservice teachers (53%) can build explanations whose language is understandable for high school students.

Regarding the criterion of *coherence and cohesion*, which focuses on the connection between the parts of the explanation as a coherent whole, most of the preservice teachers show low performance at the beginning (43%). There is also progress in the performance of preservice teachers throughout the course, and half of them can build explanations in which each of the parts is related to strong unifying ties (Cabello and Topping 2018). However, at the end of the course, there are still a significant number of preservice teachers with low performance on this criterion (21%).

B. Criteria on which performance is variable

The *sequence* criterion refers to logical progression in the construction of the explanation (Cabello and Topping 2018). From the beginning of the course, most preservice teachers manage to construct explanations with an appropriate logical sequence (53%), which contributes to scaffolding the construction of ideas. When observing the progression of preservice teachers on this criterion, a lack of continuity is identified, given that by the last explanation several preservice teachers, who had presented a high performance in the previous explanation, were not able to maintain this level of performance.

Something similar happened in relation to the criterion of *accuracy*, which refers to the conceptual precision of the explanation (Cabello and Topping 2014). Although the explanations of a majority of the preservice teachers were at the highest level of performance from the second explanation (68%), we note that in the last explanation a good number of preservice teachers failed to maintain this level of performance, and inaccuracies appeared in their explanations.

The last criterion evaluated, *completeness*, refers to the presence in the explanation of sufficient elements for the construction of the key ideas that students are expected to develop in school (Cabello and Topping 2018). Initially, the preservice teachers presented a low performance in this aspect (71%). Through the course, progress was observed in the performance of preservice teachers, but again it was irregular progress, given the decline in performance in the last explanation.

## Discussion and Conclusions

The aim of our research was to characterize the transference of the components of preservice teachers' subject-adequate science teaching explanations among different chemistry topics. For that purpose, we analyzed the explanations of teachers in a teacher education program, framed in different chemistry topics, using an analytical strategy adapted from Cabello and Topping (2014, 2018) for subject-adequate science teaching explanations.

Our findings showed that during the course preservice teachers' explanations progressed consistently on some criteria, while on other criteria their performance is variable.

*Clarity* and *coherence and cohesion* were identified as criteria on which students progressed consistently within the course. Those criteria are related to the teachers' capacity to construct explanations with a strong organizational structure that facilitates students understanding (Yeo and Gilbert 2014) and requires discourse knowledge (Lachner and Neuburg 2019). Our results show that preservice teachers who participated in this study were progressively enhancing their ability to construct adequate explanations in terms of their *form* (Yeo and Gilbert 2014), independently of the chemistry topic in which the phenomenon to be explained is framed.

Preservice teachers' performance in relation to these three criteria allows us to affirm that the recursive strategy of requiring students to construct written science teaching explanations strengthens the *form* of the science teaching explanations constructed. However, it also shows that for most preservice teachers to achieve high performance in these criteria, they may require more instances of training than those offered in the course.

These outcomes are consistent with those of previous studies that reported that preservice teachers were able to construct coherent explanations in different science subjects (Lachner and Neuburg 2019). In the case of the preservice teachers studied, we can affirm that in addition to *cohesion*, they are capable of transferring *clarity and coherence* in their science teaching explanations across topics.

On the other hand, the criteria of *sequence*, *correctness*, and *completeness* showed variable performance in preservice teachers' explanations during the course. Those criteria are related to the teachers' capacity to invoke the entities, processes, and circumstances involved in the phenomenon (Kulgemeyer and Tomczyszyn 2015), and the scientific concepts, ideas, or principles necessary for its understanding. Considering our evidence, we argue that for preservice teachers it is difficult to select the necessary theoretical references and present them accurately and in a well-connected manner (Sevian and Gonsalves 2008). Their irregular performance may be explained by weaknesses in their understanding of the subject matter (Sevian and Gonsalves 2008). Our results show that preservice teachers who participated in this study were not capable of constructing adequate explanations in terms of their *function* (Yeo and Gilbert 2014), since their performance was strongly attached to their understanding of the chemistry topic in which the phenomenon to be explained is framed.

Evidence from the performance of preservice teachers appears to show that prior disciplinary training, together with the recursive strategy implemented, was not sufficient to ensure that science teaching explanations met these criteria.

In summary, our results confirm that, for the analyzed sample, the formulation of subject-adequate science teaching explanations involved different components whose development had distinctive characteristics. The criteria associated with the *form* of the explanations, which depend on teachers' discursive knowledge, can be developed in initial teacher education through recursive strategies for the formulation of science teaching explanations among different chemistry topics. The criteria associated with the *function* of the explanations, which depend on teachers' content knowledge, require other strategies besides the disciplinary courses and recursive strategies for the formulation of science teaching explanations, to get teachers to formulate subject-adequate science teaching explanations across different chemistry topics.

Considering the exploratory nature of our study, we recognize its limitations when seeking to generalize to other contexts from the observed patterns in preservice teachers' performance when they construct science teaching explanations within their initial chemistry teacher education. Given the importance of improving the science teaching explanations of chemistry teachers (Geelan 2012), more studies are necessary to identify effective strategies to develop the explanatory capacity of chemistry teachers within initial teacher education.

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