Research in Science Education (2019) 49:1087–1106
https://doi.org/10.1007/s11165-019-9856-6

Explanations in STEM Areas: an Analysis of Representations Through Language in Teacher Education

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Published online: 30 May 2019
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Abstract
Constructing explanations of scientific concepts is one of the most frequent strategies used in the science classroom and is a high-leverage teaching practice. This study analysed the explanations provided by student teachers in STEM areas from a socio-materiality perspective focused on verbal and nonverbal language and representations. The study was conducted in a hybrid research format by scholars and a preservice teacher. First, the study compared the representational elements used by 86 student teachers to construct explanations about various concepts in a roleplay setting. Next, a positioning analysis was done by a preservice teacher, to a selection of five of these explanations focused on the concept of "force". The positioning analysis highlighted the embedded voices in the construction of explanations, with a focus on the intersection between science and language. The results showed that the student teachers created explanations as static artefacts, mainly using examples, graphs and images to clarify the concepts. The voices of learners and scientists were mostly absent from the explanations, which led to the presentation of explanations in STEM areas as finished and unquestionable artefacts, with references neither to nature nor to the history of science. We reflect on the meanings attributed to learning to be a practitioner in the context of interconnecting science and language through explanations, as a process of meaning (re)production within the classroom. Implications for teacher education are discussed in order to enhance student teachers' awareness about constructing knowledge by enacting explanations in the science classroom.

Keywords Explanation · Student teachers · Force · Socio-materiality · Positioning analysis

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Introduction

Constructing explanations is one of the most frequent strategies used in science classrooms in many countries by in-service teachers (Preiss et al. 2012; Geelan 2013; Yao and Guo 2018) and part of several science education reforms oriented towards scientific literacy (ACARA 2012; NGSS 2013; Ministry of Education P. R. of China 2011; MINEDUC 2013). Explanations in the science classroom are also called instructional explanations because they intend to enhance understanding in an educational situation, transcending the informative purpose (Leinhardt 2010), and looking for triggering comprehension (Gage 1968; Leinhardt 2010). These explanations are explicitly oriented towards an *explainee* (Kulgemeyer 2018). Explanations from this perspective are generated both in the construction of basic knowledge about a topic and the expansion, completion or adjustment of knowledge already acquired by the learners (Wittwer and Renkl 2008).

What we know about explanations comes mainly from research philosophy, linguistics, cognitive science and pedagogy. The construction of explanations involves linguistic elements and gender-specificities (Figueroa et al. 2018; Rappa and Tang 2018), causal reasoning (Lombrozo and Vasilyeva 2017; Wellman and Liu 2007) and specific disciplinary reasoning—such as biological reasoning (Legare et al. 2009), chemistry reasoning (Sevian and Talanquer 2014) or intuitive physics (Gerstenberg and Tenenbaum 2017; Kulgemeyer and Riese 2018).

Instructional practices that are central to learning during teacher education are called high-leverage practices (O'Flaherty and Beal 2018). Explaining is one of these core practices that, as part of competent science teaching, might be highly conducive to learning (Treagust and Harrison 1999; Braaten and Windschitl 2011; Windschitl et al. 2012). Indeed, Papadouris et al. (2017) have argued that working to improve explanations in the science classroom provides an organisational framework for science teaching and learning. When constructing explanations, people usually create representations, try to make sense of processes through visualisation, naturally link phenomena with their underlying causes and reframe mechanisms to promote understanding (Erduran and Kaya 2018; McNeill and Krajcik 2008; Sánchez et al. 2009; Tang and Putra 2018; Wang 2015; Yeo and Gilbert 2014). However, explanations can easily become ineffective for understanding if the representational mechanisms are not carefully selected (Wittwer and Renkl 2008) or if certain aspects of the explanation compete with others for attentional resources (Richey and Nokes-Malach 2013). As a teaching practice, constructing explanations is challenging for teachers, especially for preservice teachers (Charalambous et al. 2011; Inoue 2009; Zangori and Forbes 2013). Notably, the explanations constructed by student teachers have received little research attention compared to expert teachers or scientists' explanations (Charalambous et al. 2011; Kulgemeyer and Riese 2018; Pereira et al. 2016; Sevian and Gonsalves 2008).

Constructing explanations is also a strategy for knowledge integration, which is a dynamic process where students connect their prior ideas and experiences in the world with conceptual knowledge to explain phenomena and thus restructure these ideas. It means explanations are, from this perspective, learning artefacts that embrace elements of the nature of science (Bell and Linn 2000). We agree with Pereira et al. (2016) that as a teaching practice, explaining not only serves a communication purpose but introduces pedagogical messages that can be accepted or resisted by students, including critical elements of legitimacy, modality and disciplinary function (Leinhardt 2010). In the science classroom, constructing explanations embraces the enactment of power, authority (Pereira et al. 2016), the nature of science and the construction of scientific knowledge (McCain 2015). Nonetheless, these last facets of explanations have not been widely researched in educational literature (Rodrigues and Pereira, 2018). Even though we know that explanation resources and styles for the science classroom can be learned, research so far has rarely included student teachers or practitioners as protagonists of the inquiry or critiqued explanation construction (Charalambous et al. 2011). We have addressed this gap by conducting a study that combines researchers and a preservice teacher's views, from a socio-materiality perspective.

Conceptual Perspectives

Explanation as a Socio-Material Teaching Artefact

In science classrooms, how teachers link axioms, concepts and representations into a coherent unit gives shape to the explanatory framework (Geelan 2003). These frameworks are also used to evaluate the explanations that the students construct after a lesson because explanations act as an engine of students' understanding (Martín-Díaz 2013). Although teacher explanations are not contrary to constructivist approaches in education (Geelan 2003), their construction often lacks the inclusion of student ideas; thus, they can be potentially resisted by students (Pereira et al. 2016).

The transformation of scientific knowledge into a carefully versioned form is the essential aspect that defines a teacher explanation (Ogborn, Kress, Martins, and MGillicuddy 1996). Explanations in science education are language artefacts that contribute to the negotiation of meaning in dialogic classrooms including verbal and non-verbal expressions (Mortimer and Wertsch 2003). Gestures are communicative motor actions that enhance meaning-making and contribute to learning (Goldin-Meadow 2003; Levy and McNeill 2013). Using gestures in combination with verbal tools plays a significant role in the development of scientific concepts (Roth and Lawless 2002), since the physical environment, material actions and semiotic actions influence comprehension (Fleer 2009). Thus, explanations mediate the learning experience.

The socio-materiality perspective addresses tools, artefacts and language as part of human actions that create meaning in a social dimension that is inseparable from the interactions in the classroom (Cabello 2017). The materiality of learning is distributed relationally in the interactions of symbols in a specific space, such that social as well as physical processes can be understood as material aspects (Sørensen 2009). This relational materiality is often overlooked in educational research (Fenwick and Dahlgren 2015), dismissing for instance how space is represented in artefacts such as diagrams or images constructed in educational practices (Fenwick et al. 2011). Socio-materiality as an analytic perspective has been applied in professional adult education (Fenwick and Dahlgren 2015; Fenwick and Edwards 2013). This perspective will provide the framework for our interpretation under the assumption that explanations are socio-material teaching artefacts that create spaces, meanings and concepts through language.

Student Teacher Development of Explanations

Previous research has shown that student-teacher explanations are dependent on the content being taught; thus, some topics are more challenging for beginners than others (Inoue 2009). Additionally, the explanation practices differ according to the knowledge and beliefs of student teachers about the topics (Charalambous et al. 2011).

Explanations and models are epistemic components of science instruction directly related to the nature of science. However, understanding this requires high-order thinking skills from both teachers and students in the classroom (Erduran and Kaya 2018).

The few studies oriented towards improving student teachers' explanations during teacher education have found that explaining can be learned through rehearsal, microteaching, coaching, and peer assessment (Cabello González and Topping 2014; Charalambous et al. 2011; Hillier 2013; Inoue 2009; Kulgemeyer and Riese 2018). These alternatives are likely to guide student teachers towards the development of pedagogical content knowledge, which is a special type of knowledge used to transform erudite content into an understandable amalgam for the students' learning (Shulman 1986).

Considering that the support for student teachers to transform erudite knowledge into explanations for the classroom has been rarely reported with them as protagonists (Charalambous et al. 2011), and teacher education tends to be centred on content instead of practice (Cofré et al. 2015; Rodriguez and Kitchen 2004), we are interested in the student teachers' construction of explanations in a combined analysis from researchers' and practitioners' view points. We begin with the foundation that video analysis of the teaching practice followed by a discussion is crucial to enhancing teachers' awareness about their own classroom practices at the intersection of science and language (Gomez Zaccarelli et al. 2018; Kulgemeyer and Riese 2018).

Science and Language in Explanations

Creating meaning in science involves the use of multimodal language in the classroom (Mortimer and Wertsch 2003). Classroom discourse is crucial to promoting understanding and enactment in science education. Moreover, science might be considered to be a language in itself (Lemke 1990). Specifically, the language of explanations in the classroom has genre specificities which are particular to science and explanations (Rappa and Tang 2018). Explanations continually transform scientific knowledge in such a way to be memorable, intelligible and able to be used by students (Ogborn et al. 1996).

Prior studies have analysed structural elements of explanations connected with scientific literacy (e.g., Tang and Putra 2018), supportive and representational elements (e.g., Cabello and Topping 2018), the types of narratives constructed to create explanations (Norris et al. 2005) and the styles in which explanations can be created with students (Ogborn et al., 1996). Some examples of styles include describing the students' emergent ideas and connecting them with scientific models, telling a story that integrates visions and concepts, or inviting students to re-describe or re-interpret their ideas in the light of scientific models, terms or language (Ogborn et al., 1996). In terms of the structure of the explanation, we can recognise the coherence, cohesion, connectors and the argument of the explanation (Sevian and Gonsalves 2008).

It is clear that in the language of explanations, many resources can be used, such as metaphors, analogies, visual or physical representations, comparisons, tables, graphs, gestures and body movements (Treagust and Harrison 1999). In this study, we focus on the verbal and non-verbal elements of language that are present in explanations that student teachers use to create representations of concepts in STEM areas.

The Current Research

The general aim was to explore the construction of student teachers' explanations in STEM areas (science, technology, engineering and mathematics) in a classroom role play with a combined analysis from scholars and a preservice teacher. The purpose was to promote a reflection process on the dynamic of explanation construction at the intersection between science and language. We attempted to address two research questions. (1) What are the representational elements that student teachers from STEM areas often use to construct explanations in classroom roleplay? (2) To what extent does the intersection between science and language promote learning about the concept of force from the perspective of a preservice teacher?

One of the assumptions of the current study is that explanations are tools of and for thinking (Legare et al. 2009; Martín-Díaz 2013). Thus, we believe in the construction of knowledge through language within the classrooms. Particularly in regards to teacher education, we consider the student teachers' explanations as a product of pedagogical content knowledge (Kulgemeyer 2018; Inoue 2009) and a process of learning mediation (Pereira et al. 2016).

Methods

Design

Our study used an exploratory design. The information from the participants was gathered through observing future teachers in a roleplay classroom setting, recording their explanations and interviewing one of the participants for a deep analysis and consequent development of the findings. This is part of the participatory research paradigm (Bergold and Thomas 2012), in which participants and researchers share roles, challenging the distinction between subject/object/participant. Our study transits between *emic and etic* perspectives, with interpretations from the practice to research and vice-versa (Guzmán-Valenzuela 2016), between scholars and a preservice teacher in an exercise of horizontality.

Participants

The study was conducted in student-teacher education courses at three different universities in Chile, embedded in a regular undergraduate course about learning theories. One university was public, with large cohorts (up to 60 student teachers per year per programme), another was public with small cohorts (up to 20 student teachers per programme) and the third was private with the smallest cohort of student teachers.

Each university offered the learning theory course at a different moment in the career trajectory representing the third, fourth or fifth year students. However, the course also received a few students who took the course ahead of the regular career path and others who had not passed the course the previous year. Within the course—in which one of the authors was the teacher educator—the student teachers had to record a microteaching episode based on an explanation about a topic of their choice from STEM areas in a roleplay setting and analyse it using the theories taught in the course—behaviourism, cognitivism and constructivism. This was a regular formative activity of the course, without marks. The student teachers who voluntarily agreed to participate in the study signed a consent form to use their videos for research purposes. The Universidad de Chile's Ethics Board approved this study.

The group composition of participants is presented in Table 1:

Among the participants, we sought to identify a student teacher who showed interest in educational research and was willing to participate in the data analysis and research interviews. Following these conditions, we identified one physics student teacher in her last month of the teacher education programme. She was 24 years old, with 3 months of teaching practicum experience in physics, which was typical of the participants of this study, and had received average marks in her undergraduate studies. She considered herself to be a preservice teacher and is a co-author of this article.

Data Sources and Analysis

The first step in the analysis was to review the video-recorded microteaching episodes in order to detect regularities and differences in participant explanations. The analysis was completed by two independent researchers, and the coding process was conducted using a rubric designed to provide feedback for student teachers (Cabello and Topping 2018) which contained elements taken from a literature review with three levels of achievement. This instrument "REC" contained structural and representational elements. In this study, we focused on verbal and nonverbal elements that help students to create representations about the concepts (see Table 2). Two additional elements were added due to the socio-material aspects that might be present when constructing the explanations, taking into consideration prior research on explanations of the concept of force (Pereira et al. 2016). These were the inclusion of the history and nature of science and demonstrations or experiments in the explanations. Frequency comparison was completed for the groups to explore similarities and differences. As the group sizes were not similar, other quantitative analyses were discarded.

For reliability, 30% of the videos were reviewed double-blind against the elements of Table 2, and inter-coder agreement of 89.2% was reached. Cohen's Kappa was 0.64. The divergent marks were discussed until reaching an agreement, and the consensus was used for the subsequent steps of analysis.

The second step of the analysis was completed 6 months later and included observational and positioning analysis applied to a selection of five physics student teachers' videos about the concept of "force", with a focus on the intersection between science and language in explanations. This subsample was selected because the explanations were about the same topic. They also represented the majority of instances in which gestures and analogies were utilised by the group of student teachers according to the first step of the analysis, meaning that they were representationally rich-cases to explore.

Positioning analysis in the context of explanations as narratives (Norris et al. 2005) was applied in this research. Positioning is comprised of scenes and storylines that

Table 1 Groups of participants in the study

STEM Area	Third year	Fourth year	Fifth year	Total
Physics	7	17		24
Mathematics	4	17	4	25
Biology	10			10
Primary Science			14	14
Chemistry			13	13
Total	21	34	31	86

Table 2 Description of elements observed in explanations. Adapted from Cabello and Topping (2018)

Element	Description
Analogies, metaphors, simulations or models	Presence of analogies, metaphors, simulations and/or models in the explanation to help students interpret or represent the concept(s)
Examples, graphs or images	How examples, graphs and/or images are used in the explanation to help students construct the concept(s)
Gestures or voice inflections	How representational gestures and/or voice inflections are used in the explanation
Promoting learning from misconceptions	How the common misconceptions or students' alternative conceptions are addressed/treated during the explanation
History or nature of science	Presence of elements of the history of science or nature of science in the explanation
Demonstration or experiments	How demonstrations and/or experiments are used in the explanation

delimit actions and the meanings of what is said and done by people (Anderson 2009). The position is expressed in language, voice usage, body movements or gestures in specific or general moments (Redman and Fawns 2010), which were the markers of our analysis. We showed how a preservice teacher interpreted the representations created by her peers to explain the concept of force. This analysis has been previously used with in-service teachers in science classrooms (e.g., Redman and Fawns 2010; Flores et al. 2000). We transcribed verbatim the five student teachers' explanations of the concept, indicating in brackets the physical movements, body language, gestures and representations observed in the video to address both verbal and non-verbal language. For instance, we recorded what they pointed to, drew on the whiteboard or represented with their bodies, as Moghaddam et al. (2008) suggested. This was done to capture the participants' spatial and conceptual creations (Fenwick et al. 2011) when enacting explanations through classroom language and to analyse the voices present in the creation, which is a novel approach to explanations using the socio-materiality perspective. These transcriptions and videos were analysed in two interviews with the preservice teacher. The interviews were also transcribed and then assembled with each of the explanations in order to analyse the explanation and the critical or reflective comments in parallel. The results of the interviews were systematised as illustrative vignettes, organised into five emergent areas that appeared from the positioning analysis of the preservice teacher.

Results

In this section, we describe the representational elements that were most frequently used by student teachers in this study. We also present the results from the analysis and interviews of the preservice teacher, accompanied by vignettes with quotes from the constructed explanations on the topic of force, her perceptions about those selected, and a reflection about learning to be a practitioner in science education, highlighting the connections between science and language.

The average length of a student teachers' explanation was 9:19 minutes. They constructed explanations mainly by giving definitions with examples or images, as a way of illustrating the concepts. They did not use learners' misconceptions or misunderstandings to enrich the learning process. Indeed, if misconceptions appeared, the student teachers immediately corrected them by providing the "right" information or simply ignored the misconceptions without inquiring about their causes or underpinning ideas. This group of student teachers from STEM areas rarely used analogies, metaphors or models to explain the concepts. Likewise, the participants did not refer to history or the nature of science and used limited demonstrations/experiments to construct explanations. Figure 1 shows the distribution of the explanatory elements.

The analysis and reflection by the preservice teacher pointed to five main emergent categories concerning student teachers' explanations linking science and language:

1. Using gestures as a connection with daily life
2. Using daily-life language for favouring level-appropriate explanation
3. Using gestures to represent elements of the discipline
4. Including scientist and student voices in the explanation construction
5. Talking about the history and nature of science in the explanation

In the following excerpts, there are representative examples of these emergent areas, coming directly from the recorded explanation and the preservice teacher's analysis. Each piece of the explanation has been identified with the letter "E" and a correlative number; "ST" means student teacher, "S", the student. "PST" is used to identify the preservice teachers' reflection or remark. In each quotation, the transcription paragraph number is given (i.e. E1:2).

Using Gestures as a Connection with Daily-Life

In the preservice teacher's words, the non-verbal language expressed through gestures and body movements helps students to differentiate the scientific terminology from their use in daily life versus scientific fields. In her opinion, the teacher needs to take into account these

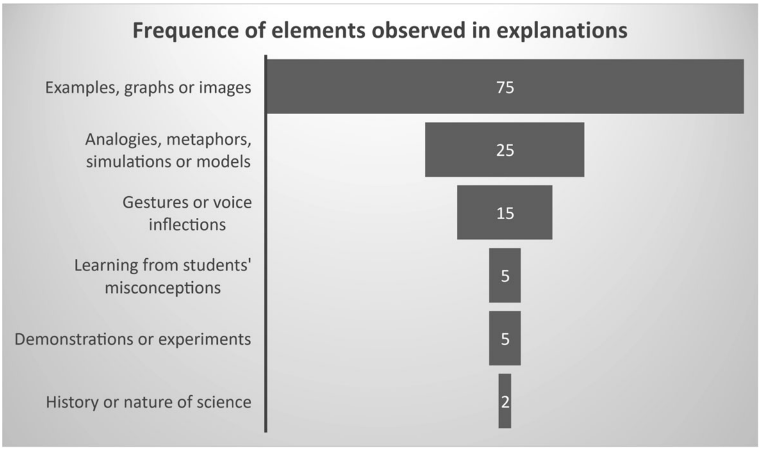

Fig. 1 Frequence of elements observed in explanations

experiences and turn them into ideas to contrast or complement the explanation for the science classroom. Further, body movements transformed into representational gestures are essential to supporting the science discourse in explanations.

Explanation	Critical-reflexive comment
We are going to study the force as something that we apply every day, for example, [when] moving the bed to get something underneath the bed (Fig. 2)... [when] moving furniture or [when] moving a chair…The concept of force is related to mass. This means it is more difficult to move something that is bigger. Let us talk directly about what [a force] relies on, which we first said depends on the mass, and also depends on the acceleration of the object. Now, it is the acceleration and not the speed because the object tends to ..., that is, if it were about the speed, the object could move perpetually without being influenced by a force. (Fig. 4) (E1:1)	He bends over and pretends to lift an imaginary bed, with furniture or with a chair… He does "this" with his hands, "perpetually", and he accentuates his voice. (PST: 2) I think it was good to do this, the gesture of muscle strength, with the gesture of pushing or moving. Because it takes something from everyday life because people use the concept of force as something that we have. However, the force is not a property of the body; force is a property of a field. Then, the body may not do anything; the force is not mine. The force occurs in interaction with me and something else. Then the force is not something that I have, it is not this (Fig. 3) to have force, but instead, a force is produced when a movement occurs. (PST:5) Regarding the gestures, the moment he pushes, one can imagine that he is moving something, but I do not know if the movements are complete. They do serve to generate a mental representation of what force is since children end up understanding this when they study gravitational force at the end of high school. The explanation is not complete because it lacks mathematical rigour that force is a vector. (PST: 6)

Using Daily-Life Language to Favour Level Appropriate Explanations

The preservice teacher pointed out that considering the grade level of the students, the language used was too advanced. The subject-specific language was introduced too early and without relation to other complementary subjects such as mathematics, and thus, the sequence of the explanation was regarded as complex. She made an interesting positioning towards the experience of students, noting that using the word "vector" was not favouring understanding because this topic is introduced much later in the mathematics curriculum. She further positioned herself as the a student teacher, because the career required her to learn elements of mathematics without understanding their connection to phenomena in physics. She noted that this lack of complementary learning caused the beauty of mathematics to be lost in the process. She changed her focus of analysis from her view as a preservice teacher to a student and a student teacher.

Explanation	Critical-reflexive comment
ST: Today we are going to study the concept of force. Does anyone imagine what the concept of force has to do here? S: The force is like "here" (points to biceps) ST: The fact that you have more muscles means that you have more strength? Can you compare and measure that? That is, do you also agree with the idea that force is something that we apply to another object? The force depends, so to speak, on the energy one has. What does a force depend on?	I think it's a lot, it's a lot to introduce acceleration as a vector in seventh grade because vectors are taught in mathematics in the first year of high school. Using mathematics in physics before learning it in mathematics does not give very good results, because one stays with the idea that mathematics was applied, but not that this mathematics [mathematical knowledge] serves for other examples as well.

Explanation	Critical-reflexive comment
S: That the chair is heavier. ST: Then we could say that the concept of force is proportional to the mass of the object to which we want to apply this supposed force (moves a supposed object). S: What is proportional? ST: If I give this chair a fast impulse, it will move more than if I apply a smaller impulse; it would depend on how quickly I move this chair. Indeed, it would have to do with the acceleration with which I move that particle, it means, it is going to be proportional not to speed but to acceleration. (E3:34–35)	This is the same as what happened to us in college, we had Mechanics the same semester as Calculus, and we used derivatives in Physics before learning them in Mathematics. We did not understand what we were doing, we did it mechanically, and then we lost, in a way, the beauty of mathematics, and that physics is a representation, but that this "derivative" can also be applied to in many other things [problems] and that sometimes it may not have direct applications as well (PST:42).

Using Gestures to Represent Elements of the Discipline

An important part of the reflection that helped position the preservice teacher in her role as a teacher was accounting for the relevance of gestures to represent aspects of the concepts in the explanation. These remarks appeared both when the gestures were used to illustrate, clarify or represent the properties of a concept (i.e. the direction of a force), or when the explanation lacked gestures that were needed to promote understanding (i.e. deformation of the physical shape of an object as a possible effect of a force). She pointed out that gestures should accompany the scientific discourse of the teacher.

Explanation	Critical-reflexive comment
Let us say that force is something that when acting on a body causes an effect, then the effects of applying a force can be two; first, to modify the state of movement of the object, and on the other hand the effect can be on the physical shape of the object (E2: 8).	When she says something "about the physical shape," she could have done something like this (crushing gesture). When I apply force [to a body] I can also deform it, not just make it move. She could have made it clear that there can be two effects when you apply a force, to produce a movement or to deform the shape of an object (PST: 9).
Moreover, you can clearly see in which direction the force's orientation is. For example, when hitting a ball, you can move it to the right, left, down or up [movement of the right hand towards each of the four directions as they are mentioned]. It has to do with the direction of the force (E2: 13).	Moreover, here, when she says that she can move it to the left, to the right, down or up, she conveys the idea that the force has direction. For example, when hitting a ball, you can move the ball to the right, the left, down or up. There she conveys the idea that the force has direction and she is showing it with her hand (PST: 14). Showing a movement with your hands conveys the idea that the force has direction and not just the magnitude which you apply (PST: 17)
One could wonder, why the Earth revolves around the Sun (movement of the right hand simulating the revolution of the Earth) and does not go to another system? (Fig. 5). (E2:47)	She makes the movement, [to show] why the earth revolves around the sun (using her right hand to simulate the revolution of the Earth) and does not go to another system. Here the gesture accompanies the speech, the Earth keeps revolving around the sun and does not leave [the solar system]."It [the Earth] does not fly away". (PST:49)

Including Scientist and Student Voices in the Explanation Construction

Regarding the voices present in the explanation construction, the preservice teacher noticed that the scientist and student voices were mostly absent from this group of student teachers' explanations. Nonetheless, in her discourse, these voices appeared as a sort of projection in which she guessed what a student would have said and thought during certain explanations. This represented a shift in the focus of analysis from her role as a future teacher towards the students and their thought process. This shift may help practitioners anticipate student thoughts while teaching. Further, she points out that scientist voices are also absent from the explanations, which might give students the idea that the concept is finished and unquestionable rather than constructed.

Explanation	Critical-reflexive comment
For example, when hitting a ball, I can move it to the right, left, down or up [movement of the right hand towards each of the four directions as they are mentioned]. It has to do with the direction of the force (E2: 14) Here we can observe a situation in which we apply a force. This child is pushing a box, and representing this method of [using] force, we can do it in a mathematical way, using a vector (E2:23)	So that is like, [voice of a student] "Okay, I move the ball. However, is it related to the force? To the direction of the force? Moreover, would the force have direction." This evokes the mental image of what could be a Cartesian plane and not just that, but that the force ... she does not say it explicitly, but she meant "force makes a ball move, when I hit the ball I can move it to the right, left, up or down" (PST: 15). However, she does not differentiate [the idea] of force between daily-life and the scientifically correct [notion]. Thus she does not account for these students' prior ideas. She can be talking and believing that the students understand the same as she says, but, if they have different underlying beliefs, what she says will not be what they understand. Children at the age of 12 use the word force, they see cartoons using the word, saying "I'm going to kill you with my force"... it is obvious that you have to take into account their underlying beliefs, if you do not, you may be giving the best explanation in the world, but where are their ideas? Their minds are not blank slates. If their minds were blank slates and you started talking about the force, you could fill them [their minds], but they already have ideas about this (PST:26–29)
When we speak of a friction force, we speak of a force that depends on the surfaces that are in contact (she puts her hands together emulating contact between surfaces). This means that if there is no contact, there is no friction force. For example, in soccer, we have friction [applied] on the surface of the ball, we have the ball that rolls on the grass (movement of the left hand simulating the displacement of a ball through the grass), but the time comes when the ball stops (shows her palm gesturing stop) and in that interaction between the surface and the ball there is friction. What do you think is the reason the ball stops? What does the ball face or advance? This thing that causes it to stop is the friction force (E5: 78)	In the end, you expect children to arrive at the right ideas [similar to] what adult scientists used to think. Things that today are now known to be wrong, but before seemed logical and there was nothing to contradict them. However, when new scientists arrived, they had to face what these people [previous scientists] who were wrong believed, and say "no". In the end, knowledge is something that is built throughout the history of humanity; it is not just that a scientist built everything we know about a concept. Force is not something that Newton did alone; Newton took previous concepts that were correct and that were wrong to reach his three laws. Then, at the end when you study Newton's Laws it's like "ah, Newton did everything," but before Newton did not the concept of force exist? (PST: 90)

Talking about the History and Nature of Science in the Explanation

In relation to the prior critique, the preservice teacher deepened her reflection and commented on the importance of including connections with the history and nature of science in the explanations. She mentioned the possibility of transforming affirmations into questions for the students in order to avoid giving a view of science concepts as "true" and "done". The references in the language of the explanation to the history of science were crucial, both to clarify common/prior ways of thinking about the concept, and to illustrate how the scientists discovered the concept or its applications.

Explanation	Critical-reflexive comment
One could wonder why the Earth revolves around the Sun (movement of the right hand simulating the revolution of the Earth) and does not go to another system? Also, among planets there are forces of attraction, which also occur between two bodies and occur between two large bodies, as it happens in the interaction between two planets. (E2:47–48)	When he asks about the movement of the earth around the sun, he could have done it without saying "kids, in our solar system, we revolve around what? The sun. And why do you think we are not flying away?" And then, he could have transformed his sentence into a question, "Is that related to the force? Why am I giving you this example in class while we are studying force?" He lacked that. I understand that this is a short micro-lesson but if this were to be transformed into [an entire] class, it is better to turn the statements into questions, [because] when you give it as a statement it [seems to be] something true, something that has already been done, but when you ask it as a question the child wonders, "why have we never left [the solar system] and continue to turn around the sun?". (PST:51)
When we speak of a friction force, we speak of a force that depends on the surfaces that are in contact (she puts her hands together emulating contact between surfaces). This means that if there is no contact there is no friction force. For example, in soccer, we have friction [applied] on the surface of the ball, we have the ball that rolls on the grass (movement of the left hand simulating the displacement of a ball through the grass), but the time comes when the ball stops (shows her palm gesturing stop) and in that interaction between the surface and the ball there is friction. What do you think is the reason the ball stops? What does the ball face or advance? This thing that causes it to stop is the friction force. (E5: 78)	I feel that it is precisely in the concept of friction force, which is something that we see every day, where we can add a bit of history, because you can say that Aristotle thought that the natural state of bodies was to stay still because things were still until moved. But then you moved them, and they became still again, but why would they become still again? Because of friction force. Then friction force is something that we experience every day ..., then this concept emerged precisely from studying human life. When they discovered that friction force existed and that friction force is what made us stop, they realised that the natural state is not to stay still, but that friction force causes us to be still after being in motion, what makes us slow down. (PST:88)

In response to the research question regarding the extent to which the intersection between science and language promotes learning, the preservice teacher referred to practicum as the privileged space that increased her awareness about the relevance of involving students in classroom science discussions. From her perspective, this means not only providing definitions of concepts but making connections with student ideas and daily-life experiences to enhance their explanations of the concepts.

From this representational view of science education, she noted that explaining science through level-appropriate language allowed students to create representations more similar to scientifically accepted models. However, from her perspective, an explanation would not be complete if not accompanied by gestures, especially with

Fig. 2 "Moving the bed" body gesture

concepts that have a clear connection with daily-life experiences, such as the concept of force. Thus, she makes a distinction between the use of the concept in diverse contexts, based on the gestures such as those used by ST1 in this study and how they mobilise the students' thought processes about what is scientifically accepted in the field of physics.

> "Being able to understand scientific words is not only useful for expanding vocabulary, but to better understand science. How did I learn the concept of force? I didn't just learn a word but learned the nature of the force. Thus, 'force' was not just a word anymore but a scientific concept to me. For me this is impressive, because I realised this while I was growing up. For instance, when I had to learn 'decomposition of force in one plane', I said to myself 'now I know it is possible to decompose force', but I had used the word 'decomposition' in a different context before, such as when a fruit is decomposed. Then, [I learned that] force could be decomposed in axes. It wasn't just a word anymore, but a concept that I understood. This is fascinating to me because I learned a new word, but it was more than a word, it was a word that helped me to understand science" (PST:112)

Adaptation to the context of teaching seems relevant for becoming a science education practitioner, as well as integrating ideas, examples or teaching strategies from peers. In teacher education, opportunities to rehearse and simulate teaching practices were also mentioned as instances to deepen the connection between science and language in the classroom.

Fig. 3 "Flexing arm" gesture

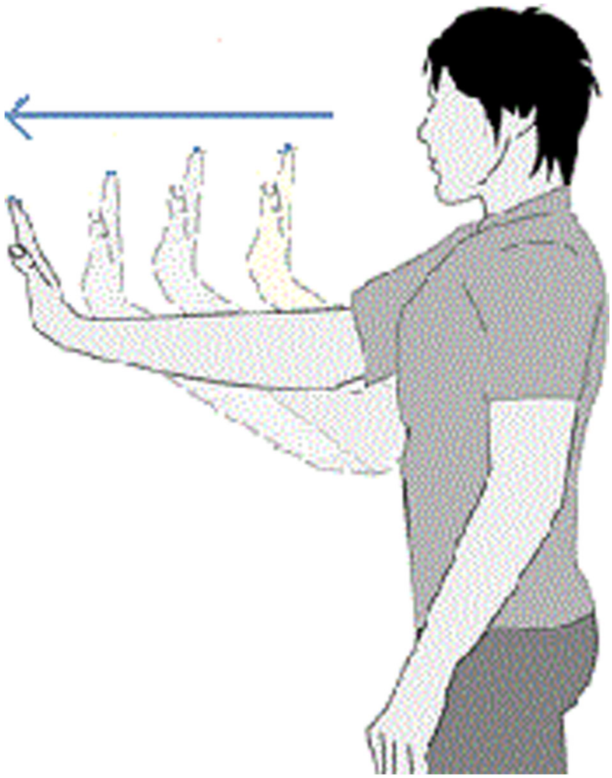

Fig. 4 "Push" hand gesture

Fig. 5 Movement of the right hand simulating the revolution of the Earth

Discussion

This research focused on analysing the explanations created by student teachers in STEM areas from a socio-materiality perspective in hybrid research from scholars and a preservice teacher.

Regarding the first research question, a comparison of the representational elements used by 86 student teachers to construct explanations about various concepts in a role play setting was conducted. The student teachers from diverse disciplinary areas created explanations that were mainly composed of examples, graphs and images to clarify the concepts, without references to either the nature or the history of science in the knowledge construction. In a few explanations, some metaphors or analogies appeared, and very occasionally demonstrations or experiments were part of the student-teachers' repertoire. Almost none of the participants addressed student misconceptions or common misconceptions as a learning opportunity during the explanation. This suggests that student-teacher explanations were constructed as static artefacts because the representational resources illustrated what is "said by science" instead of explaining the genesis of the concepts or challenging students to discover, interpret or construct the concepts themselves. It is known that teacher explanations do not necessarily lead to a transmissive style of teaching (Geelan 2013). However, in this study, we observed that student teachers tend to use explanations as a way of "transmitting truths", while having difficulty connecting them with students' experiences.

The second question referred to the extent to which the intersection between science and language promoted learning the concept of force. This was analysed from a preservice teacher's perspective. Her analysis highlighted the embedded voices in the construction of explanations as learning mediators, mainly as a process of (re)production of the same explanations the student teachers were exposed to during their teacher education. We interpret this as a lack of opportunity to question and transform the products of explanations into a different communicative context such as the science classroom. This element of the study has direct implications on teacher education practices. As teacher explanations carry elements of power and authority (Pereira et al. 2016), we strongly believe that teacher education needs to offer student teachers explicit opportunities to question and trial the implicit messages of explanations, which are embedded in classroom verbal and non-verbal language. It would include both the explanations they have received as students and the explanations they can create and rehearse as future teachers. We believe it is beneficial to position student teachers as active participants in the production of explanations, to communicate concepts to and who will have future students with diverse characteristics and needs.

The voices of students and scientists were absent in the discursive trajectory of the explanations analysed, which led to student teachers presenting conceptual explanations as finished and unquestionable artefacts. The only valuable exception was using gestures to compare or contrast the meaning of a scientific term in daily-life versus its use in a disciplinary context. Taking into account that there are several ways to include students in the formation of explanations in the science classroom (Ogborne et al., 1996), our study agrees with Pereira et al.'s statement (2016) about understanding conceptual explanations as mediational artefacts for science teaching and learning. We have seen how explanations might (or might not) involve others in the knowledge construction process, which can be produced within the classroom or serve as an exercise in reproducing explanations. The significance attributed to learning to be a practitioner through interconnecting science and language is an example of how a preservice teacher can become a critical actor in the meaning-making for science education. Furthermore, critically analysing explanations is relevant, as they are epistemic components of science instruction, directly connected with the nature of science (Erduran and Kaya 2018).

An essential part of the analysis in this study positioned the preservice teacher towards her role as a practitioner. However, the point of inflection for her learning and position change was the specificity of the domain in which words create different meanings in diverse contexts. Her identification with students changed as she repositioned herself into the decisions she might take as a future teacher when she noticed the difference between words used in daily-life versus scientific concepts. In this regard, we saw her position shift from the teacher role, to the student perspective, and then to her own experience as a student teacher when learning about a concept. This suggests that opportunities for reflection on the meaning of words in science education are highly beneficial in becoming an aware practitioner, as they are part of learning to transform knowledge for the classroom. Those opportunities perhaps anticipate student thinking, which is also a high-leverage practice as relevant as explanations (Windschitl et al. 2012).

Understanding how new teachers analyse teaching practices in simulated settings such as role-play is critical for promoting teacher education a dialogical science classroom. This includes which structures the teachers promote to support the inclusion of student interaction, student ideas and misconceptions in the process of gathering understanding. The present study resonates with the findings of Gomez Zaccarelly et al., (2018), who noted reflection to be as a critical strategy to support the professional development of teachers in improving scientific discourse in classrooms. However, we incorporated new elements which are specific to explanations, such as the five emerging from our preservice teacher analysis. These elements comprised using gestures as a connection between daily life and representative elements of the discipline, using daily-life language to favour level-appropriate explanations, incorporating scientists' and student voices in the explanation construction as a way of introducing dynamism and pertinence to the explanation, and talking about the history and nature of science as a way of understanding explanations as epistemic processes of science construction. Perhaps, these focused elements might be conducive to student teachers creating explanations in the classroom that are less resisted by students as Pereira et al. (2016) found. However, we believe internalisation and resistance are certainly part of understanding scientific concepts, principles and theories, both for students and student teachers.

This study demonstrated how explanations constructed by student teachers for the classroom present implicit messages about how scientific knowledge is built. It also exposed some of its dimensions: static or dynamic, completed or in process, vertical (from teacher to student) or horizontal (co-generated) and questionable or finished. From this perspective, an explanation as a device in science education can be part of a reproductive strategy of sharing knowledge or, from a critical viewpoint, a mechanism that allows students to relationally create their meanings about phenomena (Mortimer and Wertsch 2003). Therefore, to transcend the notion of transmitted knowledge versus learned knowledge, we recommend developing intentional explanations in which the protagonists are the students and their learning processes. This result can be achieved, as Ogborn et al. (1996) indicated, by incorporating diverse styles of communication in the frame of explanations, and, as we observed, through the verbal and non-verbal representations constructed at the intersection of science and language.

In terms of the strengths of this study, we have incorporated socio-materiality as an analytic perspective, stressing the importance of considering how the material and semiotic actions create physical spaces influencing comprehension (Levy and McNeill 2013), in this case, tracing these dimensions into the student teachers explanations. In the analysis and the chosen dimensions, we have focused on the embodiment dimension as expressed with gestures which are helpful for making-meaning (Fleer, 2009). Adopting a socio-material perspective to analyse, the explanations make the mediator role and the language artefacts between everyday concepts and scientific concepts salient. However, our study is limited to the domain of the science education, and in particular, to scientific concepts as developed in a roleplay. It could be interesting to compare with another field, to make the dynamics in explanations that are present in several areas of knowledge more evident. Likewise, the same analysis applied to or involving senior teachers could be of rich interest, especially to compare their levels of expertise to student teachers in practicum, as in this case. As a follow-up of this study, an analysis in a real classroom setting will be proposed so as to observe the contextual role of intersubjectivity and interactions with the students. This will serve to analyse the adaptation and transformation of teacher explanations during ongoing interactions.

Finally, this article proposes a methodology that helps to grasp the complexity of the student teachers' explanations in STEM areas, extending the intersection between science and language. We believe that science teachers' skills could improve if teachers were to be aware of the kind of conceptual explanations created and used with students, and their distinct messages about knowledge construction. An unfinished and debatable artefact provides space for the students to enter the conversation and gives value to their contributions as science constructors.

Funding Statement This work was financially supported by CONICYT Programa de Cooperación Internacional REDES180109, Concurso de apoyo a la formación de redes internacionales entre centros de investigación.

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