Written Reconstruction of School Scientific Experiments: The Use of Narratives in Secondary Chemistry Education

Roxana Jara[1], Cristian Merino[1], Marcela Arellano[1], Gisselle Inzunza[1], Miriam Satlov[1], and Agustín Adúriz-Bravo[2(✉)]

[1] Instituto de Química, Facultad de Ciencias, Pontificia Universidad Católica de Valparaíso, Avenida Universidad 330, Curauma, Valparaíso, Chile
roxana.jara@pucv.cl

[2] CONICET/Universidad de Buenos Aires, Instituto CeFIEC, Facultad de Ciencias Exactas y Naturales, 2º Piso, Pabellón 2, Ciudad Universitaria, Avenida Intendente Güiraldes 2160, Ciudad Autónoma de Buenos Aires, Argentina
aadurizbravo@cefiec.fcen.uba.ar

Abstract. In this chapter, we present an implementation of scientific narratives in a chemistry laboratory in secondary school; those narratives were directed to improving students' learning outcomes in the topic of oxidation-reduction reactions. The aims of our study were: characterizing the written narratives that students produced, and categorizing different 'types' of narratives related to the ways in which they approached the reconstruction of the emerging scientific knowledge. As a result, we expected to identify the application of various 'cognitive-linguistic' skills in the narratives. Students conducted a series of school science experiments following the guide of a worksheet of standard protocols. Once the lab activity was completed, students were asked to write an interpretive text that became an integral part of their laboratory reports. Our analysis on the narratives showed that many students approached the written reconstruction of the experiments in a 'descriptive' way, but other modes were also present.

Keywords: Secondary school chemistry · Narratives · Written reconstruction of experiments · Redox reactions · Lab work

1 Introduction

Along the process of teaching chemistry at school, it results essential for teachers to obtain information on what students are learning and on the ways in which they systematize and communicate what they are learning. An important means to get this information is via school scientific experimentation: teachers encourage students to formulate and answer questions on phenomena of the natural world through planning, conducting and analyzing experiments. Experimentation in the school laboratory contributes to the understanding of core scientific concepts and procedures, to the use of key scientific notions and skills in order to develop new understandings, and to the discussion of ideas on the nature of the scientific activity [1, 2].

K. O. Villalba-Condori et al. (Eds.): CISETC 2019, CCIS 1191, pp. 128–140, 2020.
https://doi.org/10.1007/978-3-030-45344-2_11

We believe that it is of the utmost importance to develop and implement school science activities that allow students to *theoretically* rebuild their knowledge on chemical phenomena; such 'rebuilding' can be fostered and at the same time made visible by engaging students in the production of written texts. The activity of reconstructing school scientific experiments through writing involves what can be called 'cognitive-linguistic skills' [3, 4]: procedures based on complex cognitive capacities and conveyed through oral, written or multi-semiotic texts, which foster the development of competences of scientific thought [4]. The process of reconstructing experiments through the use of very elaborate modes of discourse –such as explanation, argumentation, or justification– constitutes a way of gradually incorporating the normative, model-based knowledge of chemistry and of using it to make sense of the world in chemical terms.

Scientific conceptualization of the natural world is based on a set of cultural representations of the objects and interactions under study that are shared at the interior of a specific knowledge community. Although reality exists beyond its representations, theories that explain it are built on the basis of languages with strong syntaxes, invented during the long history of science. Therefore, from an epistemological point of view, reality is to a certain extent 'constructed' through sophisticated talking and writing on phenomena. Theoretical models, as conceived by the American philosopher Ronald Giere [5], can be considered the representational tools that help scientists –and students– understand phenomena, intervene on them, and construct text-based explanations and argumentations [4, 6].

Many studies have been conducted in didactics of science (i.e., science education understood as a scientific discipline) regarding the nature of students' understanding of natural phenomena. These have shown that, before formal learning, students hold their own conceptions of chemical entities and processes, and activate their own explanations on phenomena. When explaining the world, students use everyday language, which differs –in terms and syntax– from the language of scientists, thus establishing structural relations between ideas that are usually very different (and sometimes incompatible) with scientifically accepted relations.

In what has now become a classic text, Osborne and Bell [7] distinguish between what they call 'students' science' and 'scientists' science': the former comprises worldviews, conceptualizations and vocabulary that students have acquired before receiving science instruction, while the latter refers to the theoretical views widely accepted in the scientific community, which become the object of science teaching.

Science learning is a continuous and autonomous process of knowledge-building by each individual, though not in an isolated manner, but rather through rich and extensive interaction with other people and objects (teachers, peers, teaching materials, experimental artifacts, digital information). In science classes, teachers ask students to read, write and talk; in the lab, students make observations and interventions, and communicate their results, usually through 'reports'. This variety of activities constitutes a conglomerate of processes under on-going communication and evaluation, and this is precisely what enables the construction of scientific knowledge among students. Different authors [8–10] state that learning science is done through the progressive appropriation of scientific language, in association with the incorporation of new ways to see, think, talk and act on facts. As we have highlighted, such ways differ from every day, common-sense ways of seeing, thinking, talking and acting. Thus, through scientific language, students can get access to a different culture, the scientific culture, which is a historical conquest.

In this chapter, we discuss the implementation of *narratives* in a chemistry laboratory in secondary school. The ‘scientific narratives’ that we propose are directed to improving the learning of a specific topic of chemistry: oxidation-reduction (redox). The aims of the study that we report here were: 1. characterizing the written narratives that a group of students produced in order to ‘reconstruct’ their lab work, and 2. identifying and categorizing different ‘types’ of narratives, in relation to the ways in which those students approached the reconstruction of the emerging scientific knowledge. As a result, we expected to identify the organized application of a variety of ‘cognitive-linguistic’ skills in the narratives.

The thirty students participating in our study (aged 16–18) conducted a series of school science experiments on reactions of oxidation-reduction following the guide of a worksheet of standard protocols provided by the teacher. Once this laboratory activity was completed, students were prompted to write an interpretive text, which we called an ‘experimental narrative’. Those narratives, which became part of the students’ laboratory reports, constitute the corpus for our empirical analysis.

2 Theoretical Framework

2.1 Scientific Narratives

From a theoretical perspective, a narrative serves the purpose of framing and grounding any substantive linguistic exchange: “We can conceive narrative discourse more minimally and more generally as verbal acts consisting of someone telling someone else what happened” [3]. This ‘minimal’ definition makes reference to a narrator (someone saying), a recipient (someone who receives the narrative, which in this case will be called the ‘reader’), events (something that happened), and a timeframe [11, 12]. Linguists also identify other characteristics of any well-constructed narrative: e.g., structure (i.e., correct concatenation of elements), agency (actors performing actions to advance the storyline), and purpose (the aims towards which the agency is directed) [12].

The implementation of our didactical strategy involving narratives in the science laboratory aims to help moving language and thought from the everyday to the scientific. Therefore, the incorporation of narratives into chemistry teaching is valuable to students’ learning insofar as it encourages the development of the communication skills of explaining and arguing, which serve an *epistemic* function: they stimulate deeper reflection on the learnt scientific notions and they permit to construct plausible and founded explanations [12, 13].

According to Sanmartí and Jorba [14], narrative is the most common structure appearing in the texts that we usually use in everyday life. Narrative as a textual category often includes all others, as a narrative text can contain dialogues, descriptions, explanations, assumptions, etc. To be considered a narrative, the text as a whole needs to have some additional traits: cohesion, identifiable context, subjectivity (i.e., a viewpoint), and chronological ordering of events.

2.2 Characteristics of the Narrative Structure

Following [14], it can be said that the structure of a narrative is always developed in three distinct phases: introduction of the situation, development, and outcome. A narrative resorts to various linguistic elements that relate the events with time, i.e., temporal connectors and adverbs (Table 1).

Table 1. Elements in a narrative structure.

Types of text	Morphology and syntax	Key textual aspects
Written or oral texts: – Stories, reports, narrations of events, etc – Biographies – Fictions, tales, legends, myths – News, historiography, etc	Perfective verbs: distant past or recent past Elements that provide structural relations to verb tenses: – Time adverbs and locutions – Temporal connectors, conjunctions, etc	– Chronological order of events and 'narrative order' (alterations of the chronology for rhetorical purposes) – Parts of the narrative: introduction, development (with a climax), outcome ('dénouement') – Narrative viewpoints: characters' perspectives, external narrator, etc

Scientific narratives in the form of scientific reports are a discursive genre that can be used by science students to express their ideas on the scope, validity and limitations of a certain scientific position. In a study on the rhetoric of the experiment [15], Azuela states that scientific narratives in general, and experiment reports in particular, are *pieces of rhetoric* (in a conventional definition of the term), as their objective is to persuade or influence an interlocutor or an audience. Scientific discourse is a discourse of power, in which rhetoric should be understood as the use of language with the aim of being effective in all aims of communication; this includes convincing through discourse and suggesting ways of seeing and courses of action.

In our study, we conceptualize a scientific narrative as a discursive sequence that includes a concatenated set of ideas on the natural world that the author wishes to transmit, the facts that justify those ideas with reference to scientific models, the contexts of effective application of such ideas, and the author's own conceptions regarding science and its development [16].

In the context of school science, scientific language is learned by talking, reading and writing, and by thinking about these processes through the different genres employed by science. Unfortunately, too much emphasis is given to the writing and evaluation of very stereotyped texts, such as lab reports [17]. Therefore, the use of scientific narratives can be a distinct contribution, since it implies understanding scientific language, at least in some of its aspects, as genuine literary language [18], as a tool for creating and comprehending the world. In the narration of their own scientific ideas, students need to understand a set of key concepts in order to reasonably describe how they are conceiving phenomena and how they explain them to themselves and others. In the process of textualizing the ideas in an elaborate format, those ideas, and the words students use to shape them, become more and more coherent with the theoretical models that they sustain [11].

Narratives on experiments are an instrument that can have advantages for reporting on laboratory practice [9, 11, 16]. An experimental narrative is a way to reconstruct first-hand experience with a phenomenon in order to give meaning to that experience through technical language. Such reconstruction can be understood as the production of an elaborate 'factuality' combining 'real' facts accessible to experience and very stylized transformations of those facts through linguistic resources [11].

Our decision to use experimental narratives is based on acknowledging that it has been shown that they represent a means of facilitating modeling processes. Narratives are also a strategy for improving the 'memorability' of the activities; they increase interest in learning and expand the comprehension of what has been learnt. In addition, they can be used to reflect the fundamental structure of students' conceptualizations: making public students' private thought [19]. Narratives facilitate the appropriation of diverse cultural knowledge, providing a framework for dialogue between emotions, reason and experience [20]. They can be used as a tool to 'play' with experiences in a two-way reconstruction of ideas: making the incomprehensible comprehensible (i.e., giving meaning, explaining) and making the comprehensible incomprehensible (i.e., problematizing, debunking common sense). Both these epistemic actions contribute to our knowledge of the world and how we interact with it [18].

2.3 Cognitive-Linguistic Skills

Jorba et al. [17] suggests that skills are basic processes through which we deal with information, process data, draw conclusions, etc., based on acquired knowledge. Using those skills, students articulate new knowledge into already established structures formed from a set of representations of behavior and spontaneous ways of reasoning, which are specific to each individual at each stage of their development. Jorba posits that 'cognitive-linguistic' skills are those processes that are activated to produce different text types, and that they are 'transversal' to all areas of curriculum, while at the same time being formed in different ways in each of those areas. As a result, these skills cannot be approached *solely* from the perspective of the school subject Language, they must also be developed in every curriculum area in order to avoid the mistake of producing texts whose structure follows the conventional characteristics demanded by the typology but which are devoid of content. Cognitive-linguistic skills include: describing, defining, summarizing, explaining, justifying, arguing and demonstrating.

Studies [11, 14, 16, 17] suggest that, in general, when talking about skills that must be taught in order to learn science, we normally think of those that are acquired through performing scientific experiments, such as observing, proposing hypotheses, identifying and combining variables, designing experiments, collecting and transforming data, and stating conclusions. In opposition, there are very few examples that consider teaching skills related to expression and communication of ideas: describing phenomena and images related to them, defining, summarizing, explaining, arguing in favor of a thesis, or writing reports, summaries and critical assessments. It should always be considered that, in the construction and evolution of science, experiments have been a key motor, but even more important were the collective discussion of their results and their theoretical interpretation. Historical experiments are just as essential to science as the books and papers that are subsequently written in order to structure and publicize ideas.

In a scientific text, entities that anyone can easily identify transform into entities that not everyone can initially relate to, as they are highly abstract. These give meaning to the text within the framework of theoretical models [21]. This means that, when students create texts using ideas that relate to two different levels –i.e., everyday ideas translated into ideas based on a scientific theory– the way is open for them to meaningfully learn science. The linguistic skills that generally give evidence of scientific understandings are description, definition, explanation, justification and argumentation.

According to Jorba et al. [17], description, explanation, justification and argumentation are sequentially related in order of complexity. In the first place, describing produces statements about the qualities of the objects, facts or phenomena that are being described. If a causal connection is made between the description and other 'reasons', we have an explanation. If the statements and reasons have theoretical validity, showing scientific knowledge, this is justification. Finally, if the acceptability of the reasons for changing the epistemic value of the object of study is examined, we move into argumentation.

Following these ideas [17, 22], we propose that explanation, argumentation and justification are higher-order cognitive-linguistic skills that allow students to gradually appropriate the language of chemistry and give them the ability to build and communicate ideas about the world applying scientific theories.

2.4 Scientific Models and Narratives

In this chapter, we adhere to what is known as a 'semantic' view of scientific models, taken from the philosophy of science of the last quarter of the 20th century [23]. We use such a meta-theoretical portrayal of the nature and function of models in order to engage students in model-based practices when they are learning science. Semantically defined, theoretical models are the 'projections' of a scientific theory onto the world, or their 'potential realizations'. Models (of a theory) are the formal correlates of the pieces of reality that the theory intends to explain. 'Model-phenomena' (i.e., stylized reconstructions of facts by means of theoretical principles) are thus integral parts of all theories, and not their a-posteriori implementations [5, 23].

A shift in focus to a semantic understanding of models would imply paying less attention to the most formalized aspects of theories and more attention to *meaningfulness* in the learning of science [23]. Thus, the semantic conception of models opens the possibility to work with written reconstructions of experiments in school science laboratories. When doing this, models would function as the theoretical representations of phenomena that hold together the architecture of the scientific texts, including narratives.

In [24], one of us has inspected the function of the so-called 'narrative rationality' in science education, under the hypothesis that this mode of thinking can be recognized in historical scientific texts and in the texts used when teaching science. This mode of creating scientific meaning would be substantively linked to the historical development of the disciplines, which configures the famous 'context of discovery'. 'Hybrid' texts, which present scientific explanations in a narrative 'vehicle' or 'container', could prove very fruitful for science education, since they can incorporate ampliative (and especially abductive) reasoning, hypothesis generation, and the consistent use of evidence. Such texts would then require that scientific models play a very specific role: giving structure to evidence and supporting explanations. Students would use the theoretically reconstructed evidence as mediation when 'projecting' the model to the experimental results, and the detailed presentation of this process would become the core of the experimental narrative.

2.5 Students' Identified Difficulties in Redox

The literature has classified the recurrent difficulties faced by students (of different educational levels) when thinking about oxidation and reduction into two types: conceptual and procedural [25]. Conceptual difficulties include the following:

- The notion that oxidation and reduction reactions can occur independently.
- The explanation of electron transfer.
- The meaning and designation of states of oxidation.

Procedural difficulties include the following:

- Identification of reagents as oxidizing or reducing.
- Imprecise terminology and linguistic complexity hindering the identification of the involved substances and their roles.
- Solving equations that are difficult to understand, giving excessive emphasis to the importance of following established procedures (e.g., ion-electron method).

Another difficulty frequently seen is the definition of redox related to 'oxygen transfer': this idea is very appealing to students, as they can argue the participation of oxygen instead of electron transfer. A study [26] shows that when students are asked why a metal changes appearance, most of them explain it from a macroscopic viewpoint, arguing that this change is caused by the exposure of the metal to conditions such as moisture, sun, water, etc. Few students refer to the redox process, though they understand that electrons are involved in a reaction. The same study also shows that there is a conception that oxygen always participates in a redox reaction.

When students give explanations on redox phenomena, they generally have problems with the microscopic explanation and the abstraction of the behavior of atoms and the interaction of particles. They thus illustrate phenomena through facts, such as the coloring of the solution, which help identifying the experimental behavior of the system, but do not account for what has occurred.

3 Methods

The main objective of our study was to identify and characterize the narrative styles among secondary school students when they explain oxidation-reduction reactions through the written reconstruction of experiments.

Our study is based on students' original productions: the written experimental narratives. We categorize and describe 'types' of 'school scientific narratives' using two indicators: how they approach scientific knowledge, and how they use cognitive-linguistic skills.

We analyzed the narratives constructed on an experimental activity performed by students who use a protocol they were given. Once the activity was completed, the students were asked to write a text ('experimental narrative') about the subject in question (oxidation-reduction). The narratives formed part of the students' laboratory reports, and data was collected from them for this investigation. The corpus of data is constituted by the narratives written by a class of 30 high-school students (aged 16–18) who participated in the laboratory activity.

The suggested task was the following: "After completing the lab activity, we would like you to write down your experience. Please write a minimum of one page on the full laboratory experiment you have just done. Do not leave out any details: describe what you did, what you saw, what you analyzed, how you felt, and what you learned. Also try and relate the things you studied in the laboratory with processes that occur in everyday life".

Considering that data for our research is under the form of written texts with thematic unity, our data analysis, in accordance with Bardin's [27] prescriptions, is based on text segmentation into units of analysis, thus allowing identification of different meaning units that make up the narrative text. This requires assigning codes in order to be able to classify the units of register in the document, and classifying the written material for subsequent description and interpretation. This so-called 'open coding' aims to express the data in the form of concepts, corresponding to a first-order analysis. The texts were coded in order to:

- Establish regularities to identify different structural dimensions in the narratives: (a) introduction, (b) development, and (c) conclusion.
- Establish regularities to recognize different cognitive-linguistic skills in the narratives: (a) description, (b) explanation, (c) justification, and (d) argumentation.

These last four categories are understood as follows:

- Description involves producing statements that present the qualities, properties, characteristics, etc., of an object, organism or phenomenon.
- Explanation entails producing reasons or arguments in an orderly manner following cause-effect relationships.
- Justification needs providing reasons or arguments in relation to a corpus of knowledge or theory.
- Argumentation is also producing reasons or arguments, but with the main aim of persuading or convincing.

4 Results and Discussion

For the purpose of categorizing the 30 narratives that we collected, two analyses were performed: one on the structural elements, and one on the cognitive-linguistic skills that are used.

4.1 Analysis of the Structural Elements in the Narratives

Forms of Introducing: Connection to Knowledge. The first structural element is the introduction. Critically assessing allows identifying the different starting points and the ways in which students deal with their own prior knowledge and its confrontation with the phenomena. While some students only describe the instructions received, others begin by proposing ideas on the phenomenon and use their past experience as an element to frame and give meaning to what they have done (Table 2).

Table 2. Introduction

Types	f %	Examples
Summary	40	In this lab I had the experience of doing 5 oxidation-reduction experiments, in which we used 5 minerals and 3 different solutions
Descriptive	20	All the materials were placed on the table. Then the reagents were added to the solutions
Emotive	20	This lab has been a fun experience for me, because I had never done anything like this before
Reflective	10	After doing the oxidation-reduction experiment, I realized that when using different materials and reagents in a precipitation beaker, not all the materials react together
Degree of importance	10	This experiment strengthened my knowledge of oxidation and reduction

Forms of Developing: Connection with Phenomenon. Development is the longest part of the text and mainly includes descriptions of the procedure, ways to approach the phenomenon, and decision-making in the execution of the lab. Students establish a dialogue with the activity, they describe the steps taken for each redox reaction, the reflections, the physical changes observed, the successes and failures, and they even include some anecdotes (Table 3).

Forms of Concluding: Reflections on the Activity. In the conclusions of the texts, we identified more reflections from the students on the implications of the experiment, the expectations they had, their difficulties, and the expected learning (Table 4).

Table 3. Development

Types	f %	Examples
Descriptive	30	We started by identifying the solutions: copper sulphate was blue; iron sulphate was yellow and hydrochloric acid was clear; we put them separately into 5 beakers
Emotive	20	… this change was surprising because I thought it would stay the same, and so I became more interested in the experiment
Reflective	50	It seems that reaction using SO_4^{2-} with Fe generates more changes

Table 4. Conclusion

Types	f %	Examples
Emotive	40	Personally, I didn't feel anything special, maybe because I expected to see the reactions more clearly
Summary	30	From what we could see, they were all redox reactions due to the oxidising-reducing nature of the reagents
Critical judgement	30	These experiments helped me see the subject in a different way, not in the simple way I had seen it before

4.2 Analysis of the Cognitive-Linguistic Skills Present in the Narratives

All 30 narratives were again separately considered for this second analysis. They were coded according to the four main cognitive-linguistic skills that we had selected: describing, explaining, justifying, and arguing. The coding corresponds to the presence of fragments in which one of those skills can be identified.

Our analysis led to coding 138 text paragraphs, classified under the three skills that could be found (Table 5).

Table 5. Cognitive-linguistic skills

Types	n	f %	Examples
Describing	120	87	For $AgNO_3 + Cu$, the Cu plate changes from orange to silver, we also saw lumps, it gave me the impression that it was breaking apart
Explaining	15	11	We found that they were all redox reactions due to the oxidizing-reducing nature of the reagents
Justifying	3	2	We analysed the oxidizing and reducing reagents for each case, which take or give away electrons
Arguing	0	0	–

In general, description is the skill most commonly identified in the narratives of the experiment, with a frequency of 87%. This may be showing that students favor visualization of the phenomenon in terms of observation.

On the other hand, argumentation is not seen in any of the texts, showing the difficulty faced by most students when they intend to elaborate a strongly organized set of ideas in a written format that requires precision, coherence and the use of warrants or backings. This last finding may also be related to the traditional way in which science classes are conducted, beginning by presenting the 'sheer' concepts without any associated phenomena to be modeled. Such classes are neither aligned with current proposals on chemistry teaching based on a constructivist approach, nor consistent with what the philosophy of science tells us on the ways in which scientific knowledge is generated. This could explain the lack of higher-order abilities, such as explanation and justification, in students' narratives.

5 Conclusions

In the light of our preliminary results, which we have presented here, the inclusion of experimental narratives in chemical education is only the first step towards the development of higher-order scientific skills, such as explaining, establishing a theoretical basis, providing evidence, justifying, and finally arguing. Considering that a high proportion of the students are only descriptive in their retelling of the scientific experiment, it is necessary to generate scenarios in which they can be helped to make concrete advancements in the development of more robust texts that include more elaborate skills.

According to the categories employed in this study, experimental narratives favor a space of reflective 'textualization' of the scientific experiences. The narratives created by students show that for them this genre is a useful means to summarize the activity. It is our contention that narrative writing constitutes a task where students can think back on the experiment and express their impressions, and even emotions, regarding it in a more reflective way.

The multiple values of this task that we proposed lead us to conclude that it has a positive influence in students' learning, beyond what is usually achieved in this kind of activities when the traditional experiments are performed, but no written model-based reconstruction is demanded. Specifically, regarding the acquisition or consolidation of theoretical concepts, though many of the 'descriptive narratives' use more colloquial than scientific language, it can be seen that some incorporate more critical and reflective elements to account for the results of the experiments.

Villalba-Condori and his colleagues [28] state that "[t]here is a need for a pedagogical model framework, instructional design, and guides that integrate students and help reach common and desirable learning outcomes [and also a] need to analyse the necessary conditions regarding their validation". In our study, we had as an important objective the clear presentation of all the theoretical foundations, including the pedagogical model from which we designed our intervention and made didactical (i.e., instructional) decisions [29]. As a natural continuation of this first piece of research, we want to design other teaching environments in which the validation conditions of our proposal on experimental narratives can be further evaluated.

Acknowledgments. This scientific product is derived from:

- Research Project Fondecyt 11130445. Comisión Nacional de Investigación Científica y Tecnológica. Government of Chile.

- Research Project PICT-2017-3397. Agencia Nacional de Promoción Científica y Tecnológica. Government of Argentina.

References

1. Lunetta, V.N.: Learning and teaching in the school science laboratory: an analysis of research, theory, and practice. In: Abell, S.K., Lederman, N.G. (eds.) Handbook of Research on Science Education, pp. 393–441. Lawrence Erlbaum Associates, Mahwah (2007)
2. Hodson, D.: Experiments in science and science teaching. Educ. Philos. Theor. **20**(2), 53–66 (1988). https://doi.org/10.1111/j.1469-5812.1988.tb00144.x
3. Norris, S.P., Guilbert, S.M., Smith, M.L., Hakimelahi, S., Phillips, L.M.: A theoretical framework for narrative explanation in science. Sci. Educ. **89**(4), 535–563 (2005). https://doi.org/10.1002/sce.20063
4. Izquierdo Aymerich, M., García Martínez, Á., Quintanilla Gatica, M., Adúriz-Bravo, A.: Historia, Filosofía y Didáctica de las Ciencias: Aportes para la Formación del Profesorado de Ciencias. Universidad Distrital Francisco José de Caldas, Bogotá (2016)
5. Giere, R.N.: Explaining Science: A Cognitive Approach. University of Chicago Press, Chicago (1988)
6. Gilbert, J., Treagust, D.: Multiple Representations in Chemical Education. Springer, New York (2009). https://doi.org/10.1007/978-1-4020-8872-8
7. Osborne, R., Bell, B.: Science teaching and children's views of the world. Eur. J. Sci. Educ. **5**(1), 1–14 (1983). https://doi.org/10.1080/0140528830050101
8. Sanmartí, N.: Didáctica de las Ciencias en la Educación Secundaria Obligatoria. Síntesis, Madrid (2002)
9. Izquierdo, M., Sanmartí, N., Espinet, M.: Fundamentación y Diseño de las Prácticas Escolares de Ciencias Experimentales. Enseñanza de las Ciencias **17**(1), 79–92 (1999)
10. Lemke, J.: Talking Science: Language, Learning, and Values. Ablex Publishing, Norwood (1990)
11. Ramos, L., Espinet, M.: Utilizar las Narrativas en el Trabajo Experimental. In: Merino, C., Gómez, A., Aduriz-Bravo, A. (eds.) Áreas y Estrategias de Investigación en la Didáctica de las Ciencias Experimentales, pp. 197–210. Universitat Autònoma de Barcelona, Barcelona (2008)
12. Adúriz-Bravo, A., Revel Chion, A.: El Pensamiento Narrativo en la Enseñanza de las Ciencias. Inter-Ação **41**(3), 691–704 (2016)
13. Izquierdo, M.: Estructuras Retóricas en los Libros de Ciencias. Tarbiya **36**, 11–34 (2005)
14. Sanmartí, N., Jorba, J.: Strategies promoting self-regulation in science learning. In: Novak, J. (ed.): Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics. Cornell University, Ithaca (1993)
15. Azuela, L.F.: Claude Bernard, el Sebo de Vela y la Originalidad Científica (2007). http://www.medigraphic.com/pdfs/bmhfm/hf-2007/hf072k.pdf. Accessed Feb 2020
16. Marzàbal, A.: Anàlisi dels Llibres del Pare Vitoria, Director del I'IQS (1905–1955), com a Exemple de la Incorporació Progressiva de les Innovacions Científiques al Camp Docent. In: IX Trobada d'Història de la Ciència i de la Tècnica. Societat Catalana d'Història de la Ciència i de la Tècnica, Barcelona (2006)
17. Jorba, J., Gómez, I., Prat, A.: Hablar y Escribir para Aprender: Uso de la Lengua en Situación de Enseñanza-Aprendizaje desde las Áreas Curriculares. Síntesis, Barcelona (2000)

18. Ochs, E.: Narrative. In: Van Dijk, T. (ed.) Discourse as Structure and Process. Sage, London (1997)
19. Eisner, E.W.: Cognition and Curriculum Reconsidered. Teachers College Press, New York (1994)
20. Egan, K.: Imagination in Teaching and Learning. University of Chicago Press, Chicago (1992)
21. Sensevy, G., Tiberghien, A., Santini, J., Laubé, S.: An epistemological approach to modeling: case studies and implications for science teaching. Sci. Educ. **92**(3), 424–446 (2008)
22. Erduran, S.: Methodological foundations in the study of argumentation in science classrooms. In: Erduran, S., Jimenez-Aleixandre, M.P. (eds.) Argumentation in Science Education: Perspectives from Classroom-Based Research, pp. 47–70. Springer, Dordrecht (2008). https://doi.org/10.1007/978-1-4020-6670-2
23. Adúriz-Bravo, A.: A semantic view of scientific models for science education. Sci. Educ. **22**(7), 1593–1612 (2013). https://doi.org/10.1007/978-3-030-30255-9_2
24. Adúriz-Bravo, A.: Pensamiento "Basado en Modelos" en la Enseñanza de las Ciencias Naturales. Revista del Instituto de Investigaciones en Educación **6**(6), 20–31 (2015)
25. de Jong, O., Treagust, D.F.: The teaching and learning of electrochemistry. In: Gilbert, J., de Jong, O., Justi, R., Treagust, D.F., van Driel, J. (eds.) Chemical Education: Towards Research-Based Practice, pp. 317–338. Kluwer, Dordrecht (2002)
26. de Jong, O., Acampo, J., Verdonk, A.: Problems in teaching the topic of redox-reactions: actions and conceptions of chemistry teachers. J. Res. Sci. Teach. **32**(10), 1097–1110 (1995). https://doi.org/10.1002/tea.3660321008
27. Bardin, L.: L'Analyse de Contenu. Presses Universitaires de France, Paris (1977)
28. Villalba-Condori, K.O., García-Peñalvo, F.J., Lavonen, J., Zapata-Ros, M.: What kinds of innovations do we need in education? In: Villalba-Condori, K.O, Lavonen, J., Zapata-Ros, M., García Peñalvo, F.J. (eds.) Proceedings of the II Congreso Internacional de Tendencias e Innovación Educativa – CITIE 2018,Arequipa, Perú, 26–30 November 2018, pp. 9–15. CEUR-WS.org, Aachen
29. Jara, R., Merino, C., Arellano, M., Inzunza, G., Satlov, M., Adúriz-Bravo, A.: Written reconstruction of school scientific experiments: the use of narratives in secondary chemistry education. In: Villalba-Condori, K., Adúriz-Bravo, A., García-Peñalvo, F., Lavonen, J. (eds.) Proceeding of the Congreso Internacional Sobre Educación y Tecnología en Ciencias - CISETC 2019, Arequipa, Perú, 10–12 December 2019, pp. 50–59. CEUR-WS.org., Aachen