Sociocultural Explorations of Science Education 31

Mario Roberto Quintanilla Gatica
Agustín Adúriz-Bravo *Editors*

Science Teaching and a New Teacher Culture

Challenges and Opportunities

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Sociocultural Explorations of Science Education

Volume 31

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To the teachers and students of Ibero-America
who find in science a way to intervene
in the world and transform it

Original Presentation in the First Edition in Spanish

The UC Education Collection is a contribution from the Faculty of Education of the Pontifical Catholic University of Chile and UC Editions to the daily work of practicing teachers, born from the conviction of the need for texts that guide the practical work of educators in the field. Each of these titles is the result of updated interdisciplinary research and the implementation of the concrete proposals they offer.

This new book is the result of UC Editions' commitment to strengthening the education received by new generations. It is a tremendously timely and urgent book in the face of the climate challenges facing the planet. The magnitude of the environmental crises that we as societies have been witnessing demands multiple and articulated efforts. Education is a crucial area in the transformation of ways of living and relating to nature. And particularly, science education poses a privileged opportunity for new generations to acquire a vision and a definitive commitment to the ecosystems we inhabit.

Such challenges are shared on a global scale, and that is why the Ibero-American inspiration of this book is relevant. It provides contributions from authors from different countries in the region who, gathered in this edition, offer a convergent perspective on alternatives for improving science teaching.

Currently, it is crucial that knowledge is integrated and, in its interaction, allows addressing and understanding complex socio-environmental problems. From this perspective, this book is a contribution by including articles on subjects such as Physics, Chemistry, and Biology; addressing concrete suggestions on didactics of science at both school and initial teacher training levels; and covering aspects such as evaluation or educational technology.

Through this collection, the UC makes a new contribution to the educational system, this time on one of the most pressing topics of intergenerational dialogue in the face of the climate emergency that we will face in the coming decades. This expresses the public commitment of UC to the education of the country, which we hope will contribute to strengthening the work of our teachers to enhance their pedagogical practices in both school and university classrooms.

Dean of the Faculty of Education Alejandro Carrasco Rozas
of the UC, Santiago, Chile

Introduction to the Second Edition in Spanish

Sixteen years have passed since, in the prologue to the first edition of this book, whose original title was Teaching Science in the New Millennium, we wondered why it is necessary to think critically about the training of natural science teachers in Latin America. The issue of the quality of scientific education had already become, at the beginning of the twenty-first century, the subject of numerous rigorous research and innovations worldwide, with a vast bibliography accumulated after three decades of intense work. In our region, production was somewhat incipient, but very remarkable achievements could already be recognized. Our book was then based on a short but substantial intellectual "tradition." However, at the same time, many problems persisted in science classes at different educational levels and in the initial and continuing training of science teachers, which was of even greater interest and concern to us when devising the index of this book.

The new millennium arrived with the proposal of significant reforms in traditional teacher training models, subjected to enormous pressure from new social demands, common sense opinions installed in the mass media, the dissemination of results from comparative transnational studies, and the intrusion of market logic in the educational field. However, we were unwaveringly convinced that our region was practically the last bastion on the planet where a professionalizing training model persisted, which considers that natural science teachers should be trained from the beginning to the end of their careers as such, in carefully designed institutions for this purpose (universities offering "teaching courses," "teaching degrees," or "pedagogies," depending on the country, pedagogical universities, higher teacher training institutes, normal schools, etc.). We recognize that such a model is, of course, foreign in its origins: it had reached us from the rich continental European pedagogical tradition; but here it took on very rich characteristics and survived the various reformist trends that occurred in the West and that managed to blur to a large extent the specificity of professional training for teaching.

In that context, we set out to compile a book on the subject and gather in it people committed to the field of didactics of science from seven different countries. More than a decade after the great effort that such a project entailed, we reaffirm today more than ever the idea that served as the guiding principle for the original version. We are convinced that the study of science as a profoundly human enterprise provides us with new didactical forms, metatheoretically grounded, to look at school scientific knowledge and contribute, with originality and commitment, to its active transformation. The aim is to achieve quality scientific education for all children, adolescents, and young people in our region through teacher training organized with solid theoretical foundations derived from research carried out from and for our context. Therefore, the challenge was then, and still is today, for the enormous originality and power of Latin American thought in didactics of science to contribute valuable inputs to the renewal of the models that govern the training of our teachers at all educational levels, from the initial to the higher.

The book we are presenting, a renewed, expanded, and updated version of the one we were able to introduce with great enthusiasm and effort in May 2006 in Santiago de Chile, is organized around the axes of knowledge and professional practice of natural science teachers. We work on these two axes from the didactical discussion aided by the epistemology and history of science and relying on innovative classroom experiences guided by research, which function as "paradigmatic examples" of the conception of school science to which the different authors who participate adhere.

At the time when the original saw the light, we as publishers positioned ourselves around the role that universities should assume for us as spaces for critical thinking about a scientific education guaranteed by the State and carried out in public institutions under principles of equity and social justice. The academics who have authored this collective work are convinced that the university, as a privileged place for the production and dynamization of knowledge and as a leading actor in the articulation of that knowledge with social demands, must contribute with empirical findings, bibliographic reviews, critical analyses, solid arguments, original theoretical perspectives, and well-founded orientations to that education that we are foreseeing, especially, and in accordance with our professional interest, from the space of initial and continuing training of professionals who will take on the task of making it live in the classrooms.

In the first prologue, and throughout all those chapters, we were convinced that didactics of science, as a consolidated academic discipline, constituted the central engine to contribute to the generation of powerful ideas for teacher training in the twenty-first century. Today, with much more experience and a long journey of joint work, crystallized through the creation of the Latin American Network of Researchers in Didactics of Natural Sciences (REDLAD), we reaffirm that conviction and commit ourselves to put our academic production at the service of the millions of teachers that our beloved Latin America has, so mistreated sometimes from outside and from within, but a young continent with a bright future.

Sixteen years ago, we called the book a "mosaic of contributions": we had summoned, not without a certain amount of daring fueled by the enthusiasm that the project provoked in us, notable colleagues from the region and Spain to help us compose a volume that was somewhat diverse in its conceptual and methodological orientations. Today, readers will find a work with many more convergences: the incipient academic and human relationships that we were weaving at that time are now completely settled in ties of systematic collaboration, professional respect, and genuine friendship, which result in a deep theoretical and political harmony. It is then with great joy that we make this new version of the book available to our colleagues, hoping that they share with us the utopia of training Latin American "teachers" to change the world.

Teaching of the sciences for a new teaching culture is a renewed, expanded, and updated version of that book that with great illusion and effort we were able to materialize in 2006 in Santiago de Chile with the sponsorship of Ediciones UC. Its chapters, introduced here preliminarily, are organized in reference to the axes of knowledge and professional practice of natural science teachers. We work on these two axes from the didactical discussion aided by the epistemology and history of science and relying on innovative classroom experiences guided by research, which function as "paradigmatic examples" of the conception of school science to which the different authors participating in this publication adhere and which we briefly detail below.

In Chap. 1, "Scientific Thinking Skills in the Classrooms: Theoretical and Methodological Contributions to Promote and Develop Higher-Level Learning Competences," the theoretical-epistemological foundation for the promotion and development of scientific thinking competencies (CPC) in the classroom from advanced research in didactics of sciences is presented and discussed, as well as the conceptions about the nature of science and its teaching that influence the initial and continuing training of teachers. In the development of this chapter, the nature of science and learning by (and of) CPC; science teacher training and competency-based learning of sciences; theoretical bases and debate about CPC; language as a problem and instrument to promote CPC; language and the planes of scientific thinking, articulators of CPC, are delved into, ending with methodological orientations to promote CPC.

Chapter 2, "Discursive Interaction and Construction of Science in the Classroom," by Antonia Candela, an author with vast scientific background, aims to study some processes of constructing scientific knowledge in the natural context of the school classroom. In this regard, she points out that sociocultural-oriented works, increasingly with greater consensus within educational research, argue that meaningful learning not only depends on the prior ideas of individuals and their spontaneous evolution, as psychogenetic research has shown, but on the interactive sociocultural context in which it occurs. Therefore, she introduces us to the well-founded idea that to understand how science is taught and learned in the classroom, it is necessary to study the processes of constructing a shared understanding, through discourse between teachers and students, characteristic of the school situation in classrooms.

In Chap. 3, "Scientific, Didactical and Analogical Models in Science Teaching," Agustín Adúriz-Bravo presents theoretical ideas and practical proposals within the line of research and innovation in science education that deals with the nature and function of "school scientific models." This line studies the role played by representations, models, analogies, and metaphors in the construction and communication of school scientific knowledge in formal processes of science teaching within compulsory education.

In Chap. 4, “Experimental Practices in the Process of Scientific Enculturation,” Anna María Pessoa de Carvalho introduces us to the notion of scientific enculturation. What she aims to show, either with the theoretical references presented or with the examples recounted – all tested in class in basic and middle schools – is that investigative demonstration classes and open laboratories are privileged teaching activities to promote the scientific enculturation of new generations. To this end, she proposes analyzing experimental activities to discuss whether, in these classes, teachers create an environment conducive to the scientific enculturation of their students and whether they have achieved or not levels of scientific reasoning and the skills and attitudes characteristic of the sciences.

In Chap. 5, “Some Culinary Preparations as a Support to Work in the Chemistry Classrooms,” Núria Solsona i Pairó, in the introduction of the chemical change model, in the context of the kitchen, presents an interesting experience where students experimentally study the properties of some substances such as salt, sugar, oil, and vinegar. With the aim of not limiting learning to a descriptive science, they work with a particle model that allows them to understand and justify the classification of substances into mixtures, solutions, and colloids. In the school’s kitchen-laboratory, they prepare culinary dishes such as hot chocolate, milk with cereals, and jams, among others, and explain them at the macroscopic and microscopic levels.

In Chap. 6, entitled “Chemistry for Citizenship,” its author with a vast and internationally recognized background, Dr. Mercé Izquierdo i Aymeric, reflects on a “chemistry for all” and raises the urgency of definitively changing the orientation of chemistry programs, especially in the stages of basic education. She theoretically analyzes the specific contribution that didactics of science can make to this important reform and formulates a well-founded proposal for new “chemistry for all” content in schools and comprehensive chemistry at the university.

In Chap. 7, “Reading in the Process of Construction of Scientific Models,” Anna Marbà Tallada, Conxita Márquez Bargalló, Isabel Pau, and Àngels Prat Pla develop and deepen the value of language and particularly reading as an interactive process, between the text and the reader, in which the mental representations constructed by them are the result of the superficial structure of the text, their prior knowledge, but also the experiences present in the sociocultural context that accommodates them and where they learn science in different linguistic formats.

In Chap. 8, “Reflective Dialogic Journals in the Pre-service Biology Teacher Education,” Dr. María Inés Copello Levy aims to share with teacher training professors and student teachers, especially in the area of natural sciences, some considerations regarding a work that aims to think, analyze, evaluate, and apply a teacher training model. The process, the author clarifies, is based on the commitment to train a creative, autonomous, and reflective professional, capable of sharing their activities within a learning community driven by theoretical foundations and goals that are worked on and assumed as shared.

In Chap. 9, “Pre-service Science Teacher Education in Colombia,” Rómulo Gallego Badillo, Royman Pérez Miranda, Luz Nery Torres de Gallego, Rafael Yecid, and Amador Rodríguez examine the official documents of 22 science teacher training programs in Colombia, out of the 51 that received mandatory prior accreditation. For this purpose and within the framework of a project, they designed three matrices, one for the epistemological, another for the didactical, and a third for the pedagogical aspects. In order to complement the previous information, interviews were conducted with the heads or directors of the programs, the professors responsible for them, and the students enrolled in them. Based on the results obtained and in accordance with the bibliographic review carried out, they formulate a proposal for the initial training of science teachers for Colombia. This proposal is included in the present chapter.

In Chap. 10, “The History of Science in Science Teacher Education,” Mari A. Lires carries out a thorough theoretical systematization, guiding reflections and examples that show the usefulness and necessity of including HC in teacher training, but also the need for an intervention that moves towards the institutionalization of its teaching and its integration into the teaching of experimental sciences, which could be specified, as the author refers to in the chapter, in the following aspects: (i) introduction of HC in university and secondary education curricula, (ii) promotion of research in this field, (iii) establishment of third-cycle university courses related to HC, as well as in the ongoing training of teachers, which also include the necessary epistemological reflection and finally, Lires points out, and (iv) in the development of texts and teaching materials that include critical historical visions of science.

In Chap. 11, “Modeling: A Proposal to Rethink the Science We Teach,” Pilar García and Neus Sanmartí theoretically support a curricular proposal for science teaching, related to the learning of theoretical models and with a selection and sequencing of activities aimed at the construction of such models or modeling. The ideas presented are exemplified through a work carried out with 15-year-old students about the modeling of the chromosomal theory of inheritance.

In Chap. 12, titled “Didactics of Science as a Bridge Between Research and Teacher Education: Exploring Approaches to Teaching Chemical Equilibrium,” its authors, the Uruguayan researchers Beatriz Macedo and Raquel Katzowicz work on a topic that presents difficulties in teaching chemistry: chemical equilibrium. In this research, the strategies proposed by teachers are analyzed as a means to understand their conceptions about student learning and, on the other hand, how the topic of chemical equilibrium is addressed with the intention of understanding how the identified difficulties are addressed.

In short, this is a renewed, expanded, and updated version of that book that we were able to materialize with great enthusiasm and effort in 2006 in Santiago, Chile. Its chapters, introduced here preliminarily, are organized in reference to the axes of knowledge and professional practice of natural science teachers. We work on these two axes from the didactical discussion aided by epistemology and the history of science and relying on innovative classroom experiences guided by research, which function as “paradigmatic examples” of the conception of school science to which the different authors participating in this publication adhere.

In conclusion, this is a book built from research practice for and from the classroom, in which theoretical and methodological consensuses of research in didactics of sciences are shared, and in which a body of teachers, researchers, and students with recognized international experience in our scientific community has been integrated. This materialization permeates the reflections of the authors, which constitutes one of its greatest strengths, in support of the necessary change in the initial and continuous training of science teachers, as well as the teaching and learning of natural sciences at all educational levels.

Acknowledgments in the Edition in Spanish

We would like to thank all the researchers from Latin American and European universities who made the reissue of this book possible, first published in 2005.

To the Academic Vice-Rectory and Vice-Rectory of Research of the Pontifical Catholic University of Chile, which subsidized the sabbatical period 2019 of one of its authors during the second semester of 2019, to carry out a stay at the Autonomous University of Barcelona, University of Vigo, University of Valencia, Federal University of Rio de Janeiro, and University of Sao Paulo, in whose classrooms and libraries this book was finished being reissued.

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The Editors. Barcelona, winter 2020

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Chapter 1
Scientific Thinking Skills in the Classrooms: Theoretical and Methodological Contributions to Promote and Develop Higher-Level Learning Competences

Mario Roberto Quintanilla Gatica

1.1 Introduction

Sixteen years ago, I pointed out that a fundamental issue for understanding the current process of rapid economic, political, social, cultural, and scientific transformation of developing countries was, among other relevant phenomena, the exponential growth of knowledge, along with the impact of new information and communication technologies (ICT) on the modalities of appropriation, use, and management of knowledge, as well as the various and complex changes in national and regional productive systems (Quintanilla, 2006).

In this regard, 15 years later and with new, even more complex research consolidated, I still maintain the same position with stronger convictions and arguments (Quintanilla & Vauras, 2019). The evidence that we are not in an “age of change”, but in a “change of age” and the uncertainty of our species mutilated by barbarism and selfishness in social and institutional contexts of initial and continuous teacher training and science learning in different socio-geographical and institutional contexts, is telling us something, and we must listen carefully. The fact is that current scientific and technological education continues to insist, with nuances in our countries and at different educational levels, on a curricular reference of science and science teaching of a rationalist, empiricist, and instrumental type, which was shaped since the Industrial Society at the end of the nineteenth century. This has been an evident obstacle to promoting higher-level cognitive-linguistic skills in students that allow them to theoretically interpret the world in which they live to intervene and transform it with a critical and responsible citizenship perspective (Izquierdo et al., 2016).

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Considering the above, the main purpose of this chapter is to describe the theoretical-epistemological foundations of the promotion and development of scientific thinking skills in the classroom from advanced research in didactics of science. My purpose, as it was 16 years ago, is to introduce teachers to how to identify, characterize, promote, and develop those skills in students according to the guidelines offered by metasciences such as the philosophy and history of science and didactics of science. I believe that this analysis is relevant, since today, after more than a decade, we have specific research that allows us to interestingly and promisingly link the epistemological knowledge of natural science teachers with their original evaluative and formative practices for the promotion and development of scientific thinking in students, using the history and philosophy of science as an example in this task (Izquierdo et al., 2016).

My idea is, in the first place, to delve into some theoretical dimensions about the promotion and development of scientific thinking skills in secondary students and science teachers in training and in practice in different learning environments and conditions, from a naturalized view of science, which we have been advancing in a number of research projects during the last decade.[1] In the development of this chapter, I will refer to the following sections to facilitate the understanding of the topic and the complexity it has for classroom work.

- Nature of science and learning by (and of) scientific thinking skills
- Science teacher training and competency-based science learning
- Theoretical foundations and debate about scientific thinking skills
- Language as a problem and tool for promoting scientific thinking skills
- Language and the levels of scientific thinking, articulating scientific thinking skills
- Guidelines for promoting scientific thinking skills

At the end of the chapter, I suggest some instruments and methods that can collaborate with the promotion and development of competent subjects in the classroom. Let's begin then.

1.2 Nature of Science and Learning Scientific Thinking Skills and About Them

Over the last 50 years, significant changes have occurred in the way formal, non-formal, and informal scientific education is conceived and carried out. The so-called new science education now targets all audiences and educational levels, setting ambitious goals, not without a certain degree of utopia, around the need to

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[1] In the various FONDECYT projects 1,070,795, 1,095,149, 1,110,598, 1,150,505, as well as in AKA03/04 project with Finland financed and sponsored by the National Commission for Scientific and Technological Research of Chile (CONICYT) and the Academy of Sciences of Finland.

train fully-fledged citizens capable of intervening in the world to collaborate in its transformation. Currently, there is consensus in the academic community of didactics of science that these objectives require a new curricular component, called the nature of science (Matthews, 1994; Adúriz-Bravo, 2005). By nature of science, we mean a set of metascientific contents (mainly from epistemology, history of science, and sociology of science), eclectically and pragmatically selected and strongly transposed, which can have value for quality scientific education for all (Hopkins et al., 1996; Quintanilla, 2019; Quintanilla et al., 2017). Thus, research in the last decade on didactics of science regarding teacher training highlights the need for teachers to know what science is, why it is taught, what the nature of science (NOS) is, how science is learned, and what teaching methods or strategies facilitate deepening the development of scientific thinking competencies (hereinafter STC). The results show that science teachers give little or scarce importance to the philosophical aspects involved in didactics of science as a discipline when promoting and developing STC in students.

Now, the analysis of science images, learning, and teaching are persistent in teachers and show the existence of different ways of understanding and acting on these aspects, namely: A significant number of teachers consider science to be a set of established knowledge, facts, laws, and formulas established by a special type of people: scientists, as well as promoting cultural androcentrism in science (Quintanilla & Solsona, 2019). They also assume that science perfectly explains reality and consequently "tells the truth". Regarding students, they believe they come to the classroom with an "empty mind" in terms of scientific knowledge, so their way of teaching science consists of exposing the contents, experimental demonstrations, using all necessary didactical resources, asking and correcting students' "errors" as soon as they appear; well-prepared classes by teachers and students' responsibility to study guarantee that they learn science, without understanding the complexity of scientific knowledge in all disciplines, as proposed by Caamaño et al. (2020) for the teaching of chemistry in particular. This is a traditional model of science teaching that favors a more reproductive and simplistic stance on scientific knowledge. Other teachers interpret science as a form of discovery learning that can be applied in three different ways according to the curriculum's objectives: (i) inductive, accumulation and ordering of data leading to new conclusions or generalities, (ii) deductive, combining and analyzing general ideas to produce specific definitions, and (iii) transductive, relating two elements or concepts, highlighting those aspects in which they are equal. In this sense, teachers are aware that since scientific knowledge cannot be learned "easily," the most important thing is to teach students to work with the scientific method so that they can apply it and, therefore, when teaching science, they provide materials and activities that motivate them to verify, inquire, and ask questions about the topics they are taught and demonstrate each step in an orderly manner; they design laboratory work where the student practices and the teacher observes whether the student adequately understands the scientific method. They also believe that students' thinking matures with age (according to Piagetian principles), so if they do not learn, it is because they have not yet reached the corresponding stage of development of the operations that allow them access to that specific and formal knowledge, not considering cultural, linguistic, or social context aspects in learning science (Quintanilla et al., 2017; Quintanilla, 2019). Consequently, it is necessary to adapt scientific content to the students' developmental stage and teach them scientific methodology since, under ideal conditions, they can rediscover science. This teaching model has been called the discovery model and has been widely controversial for science learning.

In the face of this model, a more protagonist philosophical alternative for students emerges, where it is considered that science is a human construction with a temporary character, as it depends on the historical, political, and social moment in which this knowledge is built, which tries to explain reality based on the elaborations of scientists, which in turn are validated within their community, through rational, empirical, and utility criteria, both known and agreed upon (Izquierdo et al., 2016). The learning conception underlying this image of science considers that the student's mind is full of ideas and learns if it is able to relate them to the new information that the teacher intentionally provides in a timely manner. The teacher is interested in knowing these ideas, making them explicit and conscious in the subject who learns, thus promoting activities that encourage doubt, conflict, interaction between their ideas and those of others, challenging them to predict and explain, all of which allows them to progressively develop more complex and elaborate arguments and explanations in the face of theories that explain different phenomena, which resemble those generated by the scientific community in the history of science itself (Quintanilla et al., 2014; Izquierdo et al., 2016).

The lack of a robust and coherent theoretical body of knowledge in science education, and that guides teachers, is perhaps one of the biggest problems that reveal this situation, continuously manifesting itself in the inconsistencies of teaching, learning, and evaluation practices when promoting quality competency-based learning in their students, an issue that I will develop further later. We believe, therefore, that the nature of science, as an emerging curricular component, would help us develop genuine school scientific activity in the classroom (Izquierdo, 2000; Izquierdo & Adúriz-Bravo, 2003), in which different higher cognitive and linguistic processes are activated and developed, typical of scientific research, which can contribute to the development of powerful scientific thinking competencies, and at the same time develop higher learning that facilitates students to think with theory about the facts of the world (Izquierdo et al., 2016; Sanmartí & Izquierdo, 1997). Among these higher psychological processes (procedures, skills, attitudes, abilities, competencies), several could be mentioned that seem extremely relevant: explanation, argumentation, analogy, reasoning (deductive, inductive, abductive); the generation and testing of hypotheses; problem-solving, ordering, categorization, and data processing, and the presentation of scientific information, modeling, and narrative, which are the most evident support for the development of STS and can be guided in classroom management, and constitute a substantial methodological and epistemological framework to modify evaluation processes and systems as well as attitudes towards science class (Jiménez-Aleixandre & Gallástegui, 2011; Muñoz et al., 2019). From this point of view, we have assumed for more than a decade that Giere's Theory of Models Giere (1992, 1999) can find an appropriate and educational path for the transposition of scholarly knowledge in the science class, which seems to be very interesting and promising for addressing teaching, learning, and evaluation as a process of subject development that learns, as it promotes reasonable connections between theoretical models (the world of ideas, thought), and the real system (experimental work, manipulation of reality, activity, experience) seeking to establish similarities through theoretical hypotheses and linguistic entities that relate them (Giere, 1994; Quintanilla, 2012b). In this way, science is thought, done, and expressed, permanently connecting these three components without separating theory from the empirical. We assume the elaboration of theoretical models both of the phenomena we are working with, of the instruments we are using, and of our intervention in the real world. An interesting idea postulated by this model or image of science is hypothetical rationalism or moderate rationalism. This means that if a scientists has a goal, he or she goes towards it by proposing how to do it "on his/her way to the goal". In short, scientific communities and individuals know how to assess whether they are "adequately" closer or further from the goal they have set, based on a common construction of a paradigmatic fact and the interpretation of this from different perspectives of the same phenomenon, for example, a diversity of scientific explanations in students about why a candle burns. In this sense, the study of how a scientific community functions, what its "criteria of rationality" are, etc., brings us closer to this moderate rationality to understand the science we teach, and the variety of objectives we propose for teaching, learning, and evaluating STC. We believe that one of the main purposes of today's scientific education is to enable children and young people to autonomously and critically implement these cognitive-linguistic processes to give coherence to their theoretical thinking, discourse, and action on the natural world, in order to make sense of it, actively intervene in it, make informed decisions, and establish robust value judgments that contribute to citizen culture and the promotion of peace and democracy. It is unavoidable to address the STC system and how they appear in the formative process; that is, the formation of thought as a pedagogical and didactical task, which cannot be fully carried out without the system of situations and evaluation devices, which make both identification and the corresponding formative and formative process feasible (Quintanilla, 2012b; Izquierdo-Aymerich, 2017). This task can only be successfully carried out with a formative conception and action, which incorporates the learning of natural sciences at all levels of schooling from the initial stage to the university level, in a different way than has been historically done in our countries, in which evaluative situations are real and deeply educational and emancipatory; that is, forming individuals with the abilities to know, know how to do, know how to be, and know how to live together. In this regard, the emergence of a model of science and the development of scientific thinking as deeply human activities is urgent: made by humans and for humans (Izquierdo Aymerich, 2000, 2017; Henao et al., 2010).

1.3 Science Teacher Education and Competence-Based Science Learning

Today, no one doubts that scientific and technological knowledge constitutes a significant and transcendent reason and purpose in promoting and developing the quality of life that should be on a human scale. In itself, it constitutes a particular and extraordinary status in decision-making related to different aspects of our daily life and planetary life when we discuss such priority, controversial, and complex issues as climate change, global warming, or other socio-scientific problems. The scientific and professional knowledge acquired by teachers should be valued for its complexity and genuine commitment and social intervention and transformation in what has been called the Anthropocene era (Equihua et al., 2016), which, from the evidence provided by advanced research in didactics of science, as well as international trends on professional training models in the area of science teachers, would be achieved through an active, continuous, dynamic, permanent, and protagonistic construction process of each subject, where previous conceptions and their own history as learners would be fundamental for understanding explanatory theories and models both about and on the nature of science in learning processes, as well as in the construction of specialized knowledge. Thus, school scientific learning (ACE) can be promoted and developed through systematic confrontation based on error, self-correction, and successive approximations that start from students' previous ideas about specific scientific topics and tend to modify them until they reach conceptual elaborations closer to scientific ones, becoming increasingly aware of how and why to achieve it (Kind, 2004). In this way, this process is identified with a rational and reasonable, emotional, cultural, linguistic, and pragmatic activity, contributing to the development of scientific knowledge understanding with all its facets and complex dimensions. From these orientations, we value autonomy and self-regulation in learning: students are conceived as active thinkers who construct personal meanings and develop their thinking system through individual and social intellectual exercise that allows them to ask questions and explanations, discuss their ideas and arguments, make mistakes, and find their own solutions to the problem at different levels of analysis of thought that, intentionally, the teacher proposes for valuable intellectual challenges (Alzate, 2012; Labarrere & Quintanilla, 2002; Labarrere, 2012).

Similarly, it is necessary for all this to enable students to understand how they are developing their thinking, not only to learn (or know) theories, methods, and specific languages about and concerning sciences but also to prepare them for life and professional success, addressing, among other things, the diversity and heterogeneity of socio-educational and cultural contexts of the science classroom in inclusive and multicultural spaces (Quintanilla & Vauras, 2019; Quintanilla et al., 2017). If natural sciences in all formal teaching processes have ceased to be seen as an eccentricity or sophistication characteristic of proposals or contexts that seek to differentiate themselves at different educational levels to favor quality learning, as we have pointed out in other recent publications (Quintanilla et al., 2017), today it is evident that this teaching and this science must respond to an ethical imperative that emanates from the conception that our childhood, adolescence, and youth need to be valued as citizens (subjects of rights) and science as an integral part of our culture, key human activity; creation of humanity and at the service of humanity as well as an instrument to know, understand, appreciate, and coexist in our world, in permanent and complex transformation, where socio-scientific problems are a tremendous contribution to the science class (Díaz & Sierra, 2019; Quintanilla et al., 2011).

The contributions of advanced research in didactics of science and their transfer to the classroom have been challenging the training and professional development of science teachers for several decades. The transformation that has occurred in what it means to learn science and its educational purpose makes us question the type of knowledge required by science teachers, and the principles and orientations to implement teaching according to the techno-scientific contexts and times in which we live (Occelli et al., 2018). This has not been alien in Chile to these demands, and since the return to democracy in the nineties, they have been implemented.

Reforms and the promotion of innovation in training and professional development have been carried out through public policy initiatives and various projects aimed at strengthening initial teacher training.[2] However, the efforts and innovations deployed do not seem to have had a significant enough impact for the required transformations.

Our contributions to this line of research are the result of work that began more than two decades ago at the Pontifical Catholic University of Chile with various national and international training, research, and scientific dissemination projects[3] that have allowed us to define what STS students should develop in the context of learning preschool and school sciences, as well as in the initial and continuous training of teachers in specific disciplines (chemistry, biology, physics); design and implement teaching sequences for various scientific contents and validate evaluation strategies that allow us to characterize how students develop these competencies continuously, dynamically, and permanently. This research work has allowed us to account for the various ways of thinking that students and teachers put into play (and dispute) when (re)constructing scientific meanings in science class, corroborating that epistemological approaches persist that respond to reductionist visions of science, its method, and teaching. At the same time, considering the fundamental role of teachers in the development of STS, we have proposed a model of continuous teacher training aimed at the professional development of early childhood educators and science teachers at the elementary and secondary levels, which has revealed their different scientific rationalities when teaching, learning, and conceiving the world (Orellana et al., 2018). In the context of this training and professional development space, we have reported that the analysis of metascientific aspects (historical, sociocultural, epistemological, and didactical) constitutes a significant contribution

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[2] Inicial%20en%20Chile.%20AVALOS.pdf. Initial Teacher Training. Beatrice Ávalos (2004).

[3] In which researchers from the Latin American Network of Research in Science Didactics REDLAD from universities and advanced research centers in scientific education in Argentina, Colombia, Mexico, and Brazil have been integrated.

for educators and teachers, which favors the transformation of their teaching practices, and can contribute to the development of quality learning with equity (Quintanilla et al., 2014; Quintanilla & Solsona, 2019). Based on these experiences developed by our laboratory (www.laboratoriogrecia.cl), which have focused on the continuous training of science teachers, we have identified key aspects to promote the training of competent subjects in science, among which we can highlight the following: insufficient representation around competencies and the competent subject; an individual conceptualization of competency development, to the detriment of the collective components of competence and competent action; a marked emphasis on products and not on processes; the design of training situations involving tasks and situations that do not correspond to real problems; scaffolding for competency development that generates automatisms that hinder the flexible and creative behavior of students and insufficient work with the products of competent action, inscribing it only in the academic context, without highlighting its projections in the context of science and restricting the possibilities of change at a personal level and in the cultural spaces where students' action takes place (Quintanilla, 2012a; Quintanilla et al., 2017). On the other hand, Cofré and Vergara (2010) argue that most training programs maintain a traditional view of science teaching, focused on content rather than skill development and critical thinking, and a decontextualized understanding of scientific activity, far from everyday life and unrelated to the historical aspects of science. They report that, in science teacher training programs for secondary education, the proportion of courses related to scientific disciplines represents on average 45% of the curriculum and with significant variation between different training institutions, careers with 30% and careers with more than 60%. That pedagogical training corresponds on average to 18% of the plan and its variation in universities is between 9% and 30%. They also note that areas such as research in didactics represent an even smaller percentage, around 6% in the study plans, even though these are recognized as central themes for the training of science teachers in previous research (Carrascosa et al., 2008; González Weil et al., 2009).

From another perspective, a study on beginner science teachers, conducted by Gaete and Camacho (2017), reports some provisional conclusions about their initial experiences in professional practice. The first of these refers to the fact that regardless of the training path taken, concurrent or consecutive, whether it is reflective pedagogical training or standards-based training or the work experience lived, none of the beginners imagine new possibilities for science in school other than "covering material." They do not approach it from transformative perspectives, nor do they project their teaching with the aim of forming critical citizens. Socioscientific, environmental, and/or sociocultural issues are absent from their practices, even in those who graduate from programs whose graduate profiles and study plans aim to promote such positions (Gaete & Camacho, 2017).

The authors project the above as evidence of the prevalence of common practices in scientific education in Chilean teacher training programs, which would obey a rather traditional conception of scientific knowledge and the practices of its professionals, which permeates through training regardless of the profile and established seal to guide training not very different in all universities in the country and the region. In this context of transition in which science teacher training in Chile is found, where the efforts and actions implemented are still insufficient to address the demands of the current vision and purposes of science education for the training of young people attending secondary education, the development of initial training standards for chemistry teachers for secondary education constitutes a controversial issue that seeks to make explicit and exemplify, in a concrete way, the minimum knowledge and performances that, in our opinion, a novice teacher requires and serves as guidance for training institutions to assume the challenges that currently present the initial training of specialist teachers in this disciplinary area.

Based on what has been presented so far, we can infer that the different approaches given to scientific thinking and its competencies come from various research areas, of which cognitive psychology and metascientific disciplines such as didactics of science stand out. Concern for the issue is not recent; in the sixties, we can find in Khan (1962) works that address two effective methods for the development of scientific attitudes, excursions and the inductive-deductive method. Today, a third is proposed: the analysis of common events, giving emerging relevance to creativity in science and its teaching (Labarrere & Quintanilla, 1999). Maudsley and Strivens (2000) argue that it is preferable to develop scientific training as a durable activity, a positive, flexible process, with metacognitive control (such as learning better), sensitive to context, emotional and rational, that responds to positive and negative events, differentiating itself from academic thinking that is normatively passive, receptive, descriptive, and contemplative. The authors mention that a competent professional must have a broad view of the world, including realistic notions of scientific evidence, keeping it under surveillance by reflective skepticism through metacognition (Angulo, 2012; Labarrere, 2012; Quintanilla et al., 2010).

In this field of new perspectives and innovations in professional training and the purposes of education, the emergence of a "change of era" is justified, as Latin American intellectuals with vast experience such as Frei Beto[4] have been arguing in recent times, and the need for a "new teaching culture of science," the initial and continuous training of teachers for a new society. The classroom should overcome reductionist and dogmatic learning options and promote in students the development of scientific thinking competencies (STS) and higher-level cognitive-linguistic skills (HCL), with the aim of fostering social integration, the development of creative thinking, and a citizenship committed to the dynamic gear of social and economic growth, with democratization not only of political processes but also, as I mentioned earlier, of socioscientific issues.

Consequently, the establishment of a new global educational framework genuinely prompts us to take a step forward in the perspective of overcoming the dependence of education, teaching, and learning on habits and models or theoretical

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[4] Carlos Alberto Libânio Christo, better known as Frei Betto, is a Brazilian Dominican friar, liberation theologian. Author of more than 50 books of various literary genres and religious themes. His treatment of theoretical analyses provides substantive evidence that interestingly links the history of science with culture, politics, and education in times of crisis of the neoliberal model in Latin America.

visions of learning in the “classically academic” sciences. The activity that the students develop makes them aware of their mistakes, and these become a link to access and re-construct (or reconfigure) more complex scientific knowledge, preventing, at first, what seems understood and integrated from being forgotten, allowing the initially overcome representations to resurface. Often, it is difficult for teachers to delve into the ideas their students have about different knowledge or specific scientific notions; moreover, little time is usually devoted to interpreting the meaning they have for them of an unexpected statement that arises in a natural exchange or debate of ideas. Therefore, it is recommended to resort to the instruments that have been designed from research in didactics of science and develop competencies and skills for social interaction, thus ensuring the regulation of learning in a broader and more meaningful strategic evaluative framework for students (Angulo, 2012; Labarrere, 2012). Next, I will refer to the theoretical contributions for the debate on scientific thinking competencies.

1.4 Theoretical Foundations and Debate About STC

Within the framework of school scientific activity (ACE), we are particularly interested in the development of higher-level STC in students. Although STC has been conceptualized from the most diverse epistemological directions and presents an elusive nature, our attempt has been directed at forming a representation of these that is not limited to determining the way of doing, but to highlight the qualities of what we have called a competent subject (Labarrere, 2012). In this context, the formation, promotion, and development of students’ STC play a crucial role; hence the urgency and legitimacy of their treatment in the context of teaching science and mathematics. Much of the creative inertia and difficulties that arise in students’ thinking is due to insufficient problem-solving treatment in various subjects, particularly in science, a situation that has prevailed over time and has resulted in extremely passive students who most of the time remain working on the margins of receptivity, avoiding any situation that may involve higher-level cognitive effort and the need for individual search, unable to advance beyond what they are “directly” given (handed over) by their teachers (Labarrere, 2012). Because of this, for more than a decade, we have insisted in our research and will continue to do so, on the relevance of promoting STC that allows students to face intellectually interesting and diverse problematic situations in school scientific activity, promoting thinking, exploring, arguing, explaining, formulating, manipulating, and communicating scientific knowledge in an intellectually challenging and genuine way. STC, therefore, represents or refers to a dynamic combination of attributes related to knowledge, skills, attitudes, values, responsibilities, and contexts that allow us to interpret processes of scientific learning development in a much more motivating and intellectually enriching educational environment, teaching to interpret everyday phenomena with theory (Cubillos et al., 2013; De La Fuente et al., 2013).

The determination, identification, and distinction of STC through action-research processes and metacognitive evaluative practices in the area of natural sciences have provided us with sufficient and diverse evidence that allows us to advance their cognitive and cultural function as a professional development process in different educational levels, socio-geographic, cultural, and linguistic contexts (Angulo, 2012; Ravanal, 2012; Joglar & Quintanilla, 2012; Quintanilla et al., 2017). This has been theoretically promising for explaining and better understanding the professional knowledge of experimental science teachers, promoting the development of their thinking in a systematic, continuous, and permanent way. From our perspective, the competent subject in science is constituted as an actor capable of identifying controversial situations (or obstacles) in the science class and addressing them with their own resources in the management of scientific knowledge and learning. From this consideration, the STC emerges as an attribute of the subject determined by a permanent and systematically directed performance to demonstrate the personal substrate of competent action, valuing and evaluating the way in which different subjects identify, approach, and solve situations they face in different conditions and learning environments (Labarrere, 2008; Quintanilla, 2012b).

In one of our publications linked to research projects developed in Chile (Quintanilla, 2012b), we pointed out that during the nineties, the emphasis on the development of scientific thinking skills in students grew significantly. Some research has suggested new methodologies for their promotion and development, such as personal assistants in computer science teaching (Quintanilla & Vauras, 2019). Maudsley and Strivens (2000) argue that it is preferable to develop scientific training as a durable activity, a positive, flexible process, with metacognitive control (how to learn better), sensitive to context, emotional and rational, responding to positive and negative events, differentiating from academic thinking that is passive, receptive, descriptive, and contemplative. The authors mention that a competent professional must have a broad view of the world, including realistic notions of scientific evidence, keeping it under surveillance by reflective skepticism through the continuous promotion of metacognitive processes (Angulo, 2012; Labarrere, 2012; Joglar & Quintanilla, 2012). However, the perspective of moderate rationalism in school science presents itself as an invaluable alternative to promote the development of science skills through modeling and project-based teaching (Gomez & Quintanilla, 2015).

As we have anticipated in previous sections, the notion of STC refers to a subject who has a recognized ability to face a specific problematic situation, who has a certain degree of theoretical mastery, skills, and particular resources, who has developed their thinking (among other purposes) to explore, explain, argue, describe, justify, perceive, formulate, manipulate, and introduce new ideas that allow for competent interaction in a given context, environment, and learning condition. We thus try to overcome the era of questions and instruments, materials, and resources whose designs are directive, normative, or structural, in favor of those that favor students being the "real and permanent" protagonist of the learning development process (Quintanilla, 2012a). Thus, the teaching staff becomes a modeler of scientific communication and learning processes, where the scientific questions posed in the classroom also make much sense and value and promote new and better attitudes towards science (Candela, 2018). We have been arguing in our research program for more than two decades and in various more recent publications that we understand STS as that ability to successfully respond to personal and social demands and challenges posed by an activity (scientific in this case) or any task or demand in the context of professional practice and implies cognitive and non-cognitive dimensions for a subject (teacher or student) configuring the idea of competent subject in science as Labarrere (2012) has proposed.

Each STS is based on a combination of practical and cognitive dimensions, of various orders, which together put into operation the effective realization of an action: knowledge, motivations, values, attitudes, emotions, and other social and cultural elements. A competence is a type of complex knowledge that is always exercised in a specific context efficiently. Four dimensions would configure a scientific thinking competence (STC): knowledge, context, skills, and values, as illustrated in Fig. 1.1.

Our idea is to provide theoretical guidance and epistemologically grounded instruments with the purpose of enabling teachers to identify and characterize scientific thinking skills or competences (STC) as densely as possible, and to establish the didactical purposes of each of them in different disciplines, areas, conditions, and environments of teaching and learning of school science. A significant number of efforts to improve the quality of scientific education have focused on exploring students' ideas about science and the scientific concepts taught at different levels. We try to establish an epistemological basis for teaching science in light of contemporary notions about the nature of science and how children and adolescents learn not only based on their cognitive functions but also through the cultural and

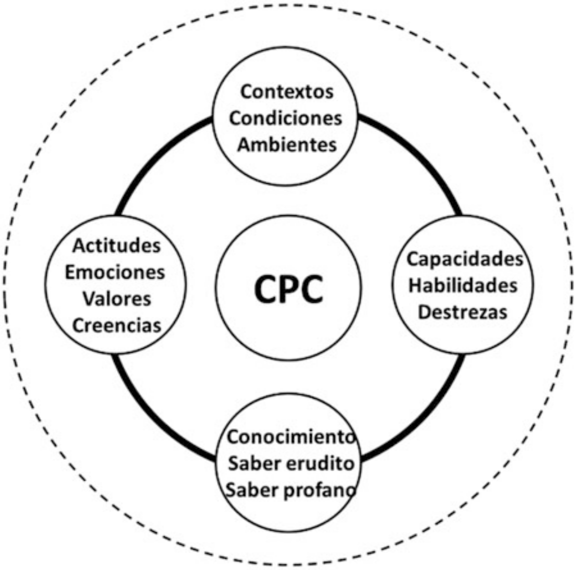

Fig. 1.1 Dimensions of scientific thinking Competence. (Author's elaboration)

value-based environments that accommodate them, which constitutes a valuable contribution to curricular reform from complementary and converging metasciences: philosophy and history of science, learning psychology and didactics, as well as contributions from sociology and the multiculturalism of science (Izquierdo et al., 2016; Quintanilla et al., 2017).

In one of our "historical" works (Quintanilla, Izquierdo and Adúriz-Bravo, 2005), we pointed out that, in our opinion, the focus should be on generating higher-order epitomic competencies (that is, characteristic or exemplary) of the sciences among students, competencies that we could call "cognitive-linguistic" (Sanmartí, 2003), since they demand the activation of complex thinking skills and the production of highly elaborated texts. Among these competencies, as we said, would be the formulation and testing of hypotheses; school scientific explanation and argumentation; the use of analogical thinking (through analogical models, concrete analogs, epitomes, similes, and metaphors); the different modes of inference; and narrative. Therefore, one of the main purposes of today's scientific education should be to achieve children, adolescents, and young people capable of making sense of their active intervention in the world, making informed decisions, and establishing robust value judgments by autonomously and critically implementing these cognitive linguistic competencies to give coherence to their thinking, discourse, and action on the natural world. Hence the importance of language in educational communication processes, not only as an instrument but also as a problem, an issue that I develop below.

1.5 Language as a Problem and as an Instrument to Promote STC

For several decades now, researchers from different fields of knowledge, whether or not metatheoretical, have agreed on the importance of language as a more than relevant component in the teaching of experimental sciences. The different evidence from research in didactology (Candela, 1999; Mortimer, 2000; Izquierdo & Sanmartí, 2000; Galagovsky et al., 2014) has shown that language is a problem not only linguistic but also cultural and social to which emotions, personal histories, ideologies, and different ways of seeing the world contribute with various purposes ranging from its descriptive legacy to visions of intervention and social transformation. Vygotsky (1996) already anticipated more than 100 years ago that our ideas filter into our words and convey not only knowledge but also feelings and emotions. From this initial consideration, words shape realities and meanings, but they also operate with an emotional charge that conditions and determines the individual subject and also the collective subject in different cultures in which we teach science (Molina et al., 2014). Consequently, we operate with a dynamic language whose semantic richness favors or hinders understanding the world and feeling an important part of its intervention and transformation, of a permanent human adventure.[5] Sutton (2003) points out that "…an important part of scientific education should be aimed at helping students recover some of the past struggles and hear the authentic voices of those who participated in the process of formulating a new way of thinking…" (p. 5). In this regard, what I have been proposing so far implies that science teachers, in particular, commit to identifying and developing activities of learning and evaluation that reveal the process of developing cognitive-linguistic skills and/or scientific thinking competencies in didactical design decisions and in the "school discursive activity of science" itself that promotes argumentation, explanation, justification, modeling, among others (Revel Chion, 2014). This implies that teachers recognize, validate, and legitimize their teaching practice from the meta-scientific status of didactics of science (Quintanilla, 2011). Language is not only a didactical problem, it is intertwined with emotions, life stories, and culture. It is that genuine word that stimulates us to think and feel our classes as strategies for the development of scientific thinking and appreciation of knowledge to promote citizenship, peace, and democracy. That is, to understand the social and political processes and the framework that is woven with science and culture; that teaches students to develop cognitive-linguistic skills for higher purposes, stimulating creativity, social coexistence, human rights, equity, justice, thus promoting the transformation of their ideas in a process that neither begins nor ends with the culture of symbols and formulas of scientific theories.

The promotion of cognitive-linguistic skills or scientific thinking competencies such as explaining the combustion of a candle, the idea of emptiness, arguing about therapeutic abortion, justifying space travel or stem cell research, should allow teachers and students to enrich, expand, and deepen different life experiences as individual and collective subjects that enhance knowing and understanding, explaining and interpreting reality, and then recreating and transforming it through the reasonable use of science, understood as a deeply human activity that models, contextualizes, and interprets the world with theory (Quintanilla & Camacho, 2008; Izquierdo et al., 2007).

What I have described so far in a very discreet and unfinished way takes on special meaning in the current context of Latin America, where the conditions and educational environments to promote these cognitive-linguistic skills are, in most contexts, "curtailed" by a savage and ruthless economy. In this regard, there is consensus in academia and scientific communities, as well as in some international organizations (UNESCO, FAO, OAS) that most social, environmental, health, among other problems, could be effectively addressed with human capital aware of the drama of the future and the disastrous consequences of the predatory action of homo sapiens, in the now-called Anthropocene era (Equihua et al., 2016). This

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[5] Many of these aspects I have developed in other recent publications such as "Language as a problem and opportunity for the development of scientific thinking. Learning to read the world through science." *Promotion and development of cognitive-linguistic skills,* Cabrera, H. (2020). Universidad del Valle, Colombia.

human capital must receive a scientific education committed to the quality of life of people, regarding which it has been established that there is consensus on the importance of a person's early years for their future development and performance in adult life, since early childhood experiences based on stable and sensitive interactions with scientific knowledge (the garden, water, food, health, coexistence), which enrich learning experiences during upbringing, contribute to providing lasting positive effects (World Bank). However, to advance in this line, better public policies are needed in our countries that promote quality scientific education, fostering these cognitive-linguistic skills from an early age and permanently, systematically, and continuously throughout the entire formal, non-formal, and informal educational process, that is, throughout life. Investigate how early or late professional development intervention situations can enable the promotion of these metacognitive competencies within broad theoretical contexts, without losing sight of scientific, value, and social aspects (Henao & Stipcich, 2008; Quintanilla et al., 2017). Next, I will refer to an essential aspect of theoretical thinking that can be identified and characterized through language, its meaning, structure, and content, an issue that we have been working on in different research projects since 2002 (Labarrere & Quintanilla, 2002; Labarrere, 2012) and that is related to the levels of scientific thinking that contribute to a higher, more stimulating, and promising understanding of science knowledge and learning, as well as its connection with the "real" world to intervene and transform it.

1.6 Language and Levels of Scientific Thinking, Articulators of STC

It is common to represent the resolution process only as a confrontation of the student with the scientific problem posed by the teacher (Labarrere & Quintanilla, 2002). In this confrontation, most of the time tense, the students try to penetrate more and more deeply into the unknown aspects of the situation, to better understand what the scientific problem is about and to find the most suitable instruments (or strategies) that allow them to access the desired resolution by the teaching staff. In this view of the process of solving school scientific problems (PCE), the facts that are relevant to pedagogical and didactical action of the teacher have to do only with what occurs in the interaction of the students with the problem or situation that has been posed to them or that they have concluded. However, one can question whether this way of understanding the processes of solving scientific problems in school, as an activity that takes place only as a confrontation of the student with the situation (mediated by the language usually of formulas), actually corresponds to what really happens when they solve problems. We have differentiated three fundamental planes in the approach to scientific problems in the classroom: the instrumental-operative (I-O), the personally significant (PS), and the relational-social or cultural plane (RS) that we have theoretically situated in numerous publications derived from research projects (Labarrere, 2012; Quintanilla, 2012b; Quintanilla et al., 2017).

The instrumental-operative plane identifies those moments or fragments of the confrontation and solution of problems in which the resources of the subject or group that solves them are focused on aspects such as the content (scientific), the relationships that characterize it, the possible solutions, and the strategies, procedures, etc. It is a rather formal and axiomatic plane from the point of view of science teaching, that is, the instruments that conventionally enable the solution of these problems according to the characteristic formalization of science in this plane (formulas, calculations, graphs, etc.). In this plane, since the student's attention is directed towards the problem, the processes of conscious control try to maintain the domain of the execution that is taking place and are usually also expressed in the anticipation of the course of the solution, especially when the solution or technique for solving it has been "mechanized". This is closely linked to the evaluation of scientific learning, since the resulting product of a problem could be correct, without the subject who solved it being aware of the logical structuring that underlies the scientific explanation or interpretative understanding of the theoretical model of it (Labarrere & Quintanilla, 2002). Some examples: Graph the volume/temperature slope; What is the valence of calcium? Define cell; Calculate the amount of solvent mass; What is the chemical change?

The movement through the personally significant plane indicates another angle of the resolution of a scientific problem. In this, the personal processes and states of the person solving the problem become relevant, and the subject's attention leaves aside the analysis of the situation, the active search for instruments, the representations of purposes linked to the expected solution, and focuses on the person, as the subject of the solution. What is relevant is the entire cognitive repertoire of the subject that is set in motion to link their personal experiences with the object of knowledge they are confronted with, overcoming the merely algorithmic view of problem resolution. Some examples: Graph the volume/temperature slope; What is, according to what you have read, the valence of calcium? Define cell; Calculate the amount of solvent mass; How do you explain the combustion of a candle? In the personal plane, the meanings and senses of the "problematic contents" are constructed. Here, the why and for what of the confrontation and resolution of scientific problems become relevant; also playing an important role are the points of view, representations, and beliefs that, about the problems, the solution, and themselves, as solvers, the subjects have, although in many cases they may be unstable or not very coherent from the logic of science, its method, and nature. From our point of view, when talking about the existence of the personal plane and the movement of the subject through it, the existence of a space is introduced in which the senses or personal meanings of the person solving the problem act and are generated, and which has to do with the significant context of their daily life or personal experience in relation to the content of the problem and how to approach it. This aspect is key to enhancing the creativity of the subjects who learn, even when the learning environments they face are limited or restrictive (Labarrere & Quintanilla, 2002).

In the relational-social (or cultural) plane, identified as the space generated in the group or collective problem-solving or in the purely pedagogical interaction focused on the solution, reference is made not only to the relationships that constitute the framework woven in the communicative processes, but also and perhaps above all, to the knowledge and representation that subjects have of these interactions, as well as to the mastery and awareness they achieve regarding the production of desirable relationships, either for the solution of the problems in question, or for the formative processes in which they are involved. Here also lies the history of the subject as an individual and the history of the collective as a group, since from these interactions (shared memory) new, more complex and comprehensive perspectives emerge to face the resolution of the scientific problem, whose final approach may have a significant dose of consensus resulting from the convergence of ideas, assumptions, relationships, experiences, etc., among all the subjects of the group. Graph the volume/temperature slope; What is the valence of calcium according to what you have read?; Define cell; Calculate the mass of solvent; How would you explain the combustion of a candle?

The displacement of the subject through "planes" of scientific thought or spaces of problem-solving for the promotion of STC can take place on a single plane or as a transition from one to another or coexisting; so that if, from the fragments of the discourse, or from the observation of the resolution activity, a certain profile of the movement is elaborated, a broken line is observed where fragments of the solution are followed, and in which it is evident that at different moments, those who solve a problem pursue different objectives, even when the common objectives of the group have been made explicit. This is very important because it involves guiding the self-regulation of scientific learning processes and the control of development planes to address them differently for each student. For example, if a student solving a chemistry problem is trying to establish what the "scientific" content of it is, whether it can be referred to atomic theory or not, and whether it is possible to coordinate a certain resolution procedure, then he is moving in the instrumental operative plane; in this case, the objectives that act refer to the understanding of the problem structure, the set of relationships that characterize it, its parts, and the solution instruments that may be viable according to "the density and coherence" of the model he has about the specific content (atomic theory). In a quite relativized sense, it can be assumed that the displacement of the "theoretical and practical thinking" of the students through one of the planes or from one plane to another presupposes a certain disconnection or more or less lasting coexistence of the other planes. Thus, when a student is trying to establish the scientific content of a problem, its structural frameworks (or networks) and the possible access instruments, he cannot be at the same time in the scientific meanings of the activity, nor in the relational plane in which these contents and meanings acquire value on the didactical assumptions of the scientific activity that we are supporting in these ideas. It could be thought that the cases in which help is requested to solve a scientific problem, that is, when the resolution is sought through the support of the other (the group/the teacher), are evidence of the displacement, through the instrumental operative and social planes, at the same time; but although we assume that the occurrence of the facts, here, is simultaneous, we must remember that the action in the relational cultural plane, as we have defined it, requires more or less conscious access, and therefore it is impossible for both purposes to emerge simultaneously in the consciousness of both the learning subject and the logical framework of the science teacher or his own peers (Labarrere & Quintanilla, 2002).

In an even more complex sense, we believe that the path of scientific training necessarily requires a didactical argumentation connected to the analysis of the various factors that have conditioned, if not determined, the ways in which learning to teach and disseminate scientific knowledge is learned, in different times and cultures. In his book Human Understanding, Toulmin (1977) sets up an interesting discussion about "conceptual change" and "scientific change" using as a basis the "problems faced by scientists" identifying three methods that allow them to be discriminated and resolved: These modes or methods would be: (a) Improve the representation or theoretical models (Thought, P), (b) Introduce new communication systems (Language, L) and (c) Refine experimental methods in phenomena (Experience, E). In Table 1.1, I synthesize these ideas below[6].

In Table 1.2, I provide some examples that allow the teacher to identify the relationships between the planes of thought and the scientific activity that guides the school task and that can be used as an instrument to "formulate competency-based questions or guide the task to a specific level of resolution in a way analogous to how the scientific community solves it" (Toulmin, 1977). It is evident that there may be nuances in the way we think about a question or an activity because the theoretical models we construct are determined at the same time by the way we have learned them.

So how do we teach students to face solving a problem and promote, for example, scientific argumentation or explanation? How to evaluate (not measure) the development of competencies in students? Currently, there is a considerable consensus that teaching the resolution of scientific problems in the classroom is one of the main means for the development of "theoretical thinking," as well as for promoting and developing specific STSs such as arguing, explaining, justifying. This fosters and encourages a "scientific school culture" in students, also generating creative learning environments rich in metacognitive density (Angulo, 2012). The transition to scientific thinking and culture in this domain of knowledge, as primary aspects to be addressed in didactical transposition, marks an awareness that learning oriented mainly to the instrumental-operational and theoretical-conceptual plane of science is insufficient for students to achieve true competence in understanding scientific phenomena. In this sense, the need to transcend the representation of students as subjects of learning and to begin to consider a "collective subject," that is, the group that works as a team and acts as a community generating knowledge and basic

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[6] I delve deeper into this proposal in the chapter "Language as a problem and opportunity for the development of scientific thinking. Learning to read the world through science" (49–74) of the book Promotion and Development of Cognitive Linguistic Skills. Contributions from Field Theory from Didactics of Science compiled by Henry Cabrera in 2019 and published in the Editorial Program of the Universidad del Valle, Colombia.

Table 1.1 Planes (or levels) of scientific thinking and their link with the problems of science

Theoretical dimensions	Categories		Structuring descriptors	Aims of the school scientific activity
Scientific Methodology to Solve a Problem	**P**	Thinking (to think)	Theories of science, statements, laws, formulas, algorithms, scientific notions, definitions, concepts.	Improve theoretical representations of science. Modeling oriented.
	L	Language (to communicate)	Speaking, writing, narrating an experiment, explaining, arguing, justifying, new rules of the game.	Improve or adjust the languages of science. Oriented to scientific communication. Can make CPC explicit.
	E	Experience (to act)	Instruments, experiments, measurements, records, calculations, filtering, distillation, purification.	Innovate experimental activities. Oriented to the activity of the subject(s), to the procedures.
Planes (Levels)of Scientific Thought	**I-O**	Instrumental or operational	Calculations, formulas, signs, definitions, measurements, graphs, weighing, drawing, noting, recording, etc.	Emphasis on activity (without subject). Emphasis on objects, actions, materials.
	P-S	Personal or Meaningful	Thought process, intellectual challenge or activity directed at a student, a person.	Directed to the learner (me, you, him/her). Intention to address a problem.
	R-S	Relational or social	Thought process, intellectual challenge or group-directed activity. Implicit or explicit contextual linkages.	Oriented to the collective subject (us, them). Intention to approach a problem cooperatively.

processes from which the scientific education of students must be carried out (personal plane, social plane). From this perspective, it is evident the need to guide students timely and intentionally towards broader and deeper aspects of the nature of science, its method, and languages. In this direction (conscious and therefore theoretically intentional), the confrontation and resolution of scientific problems play a key role, as we are interested in promoting a logical framework that contributes to a theoretically grounded and self-regulated scientific explanation by students and the professional practice of the teacher. However, we are sure that the main issue lies in transcending the mere preparation of students to face and solve problems (measure, weigh, calculate, define), and move to a more interesting and challenging context of school scientific activity for students (Table 1.2). For this, it is also urgent to understand that the evaluation of learning is a process of subject development that shapes realities and models what is learned. It is not difficult to perceive that around formal and informal evaluation revolve normative pedagogical practices, but above all, systems of beliefs and epistemological conceptions of

Table 1.2 Guidelines for the formulation of theoretically grounded questions for school scientific activity

	Levels of scientific thinking			Scientific methodology to solve a problem		
Examples of school science problems	I-O	P-S	R-S	P	L	E
Explain how you would prepare an aqueous solution in an acidic environment.	x	x		x	x	x
How would you explain the notion of particle from a solution of sucrose in water?		x		x	x	x
Describe what biological characteristics they have in common and what differentiates a bacterium from a virus.	x	x		x	x	
What are the most bioethically controversial methods of GMO experimentation in indigenous communities? Discuss as a group			X	x	x	x
Graph the slope that according to you explains the life cycle and metabolism of a heterotrophic bacterium.	x	x		x		
How do you explain the formation of cavities from an unbalanced diet?						
What does X + 3 = 6?	x				x	
Define mass	x			x	x	
What is Geocentrism?	x			x		
Represents the combustion of carbon dioxide in a chemical reaction.	x	x		x		
Draw a eukaryotic cell and identify its fundamental structure.	x	x		x		

science teachers that are resistant to epistemological, pedagogical, and conceptual change (Quintanilla, 2012b).

1.7 Guidelines for Promoting STC

For some time now, we have proposed in other publications and innovations with practicing teachers, some methodological guidelines to identify, characterize, and promote scientific competencies in the classroom through the confrontation with the resolution of specific scientific problems (Quintanilla et al., 2012; Quintanilla & Camacho, 2008). As I have also pointed out in the previous paragraphs, the movement of the learner through the planes of analysis or spaces of the resolution of a given scientific problem can take place in one of them or as a transition from one to another; so that if, from the fragments of discourse, or from the observation of the "scientific activity" of resolution, this includes, among others, the criteria for problem analysis, the theoretical models involved, and the cognitive mechanisms and strategies that anticipate the action of resolution and its meaning (Labarrere & Quintanilla, 2002). This is very important because it implies guiding the self-regulation of the processes of scientific learning and the control of the planes of development by the learner intentionally to address them and develop school scientific competencies (CCE).

Next, in Table 1.3 and based on the theoretical orientations that I have developed and discreetly deepened so far, I propose to the teaching staff a "didactical route for their lesson plan" in three methodologically sequenced stages (initial, intermediate, and closing), which collaborate in promoting and developing scientific thinking skills (STS) in the students, indicating the activities of the teaching staff, guiding questions, and purposes at each stage of the activities.

A strategy that has been widely researched and worked on by us is the use of the history of science in promoting STS, which we have shared with the international community in various publications (Quintanilla et al., 2014; Izquierdo et al., 2016; Quintanilla et al., 2017). An example published some years ago allows us to competently guide the teaching of the notion of vacuum based on a historical analysis (Quintanilla & Camacho, 2008). In the seventeenth century in Germany, Otto von Guericke, during a demonstration he carried out in Magdeburg, adapted a water pump to a wooden barrel, filled it with water, and closed it. Then, with the help of several men, he proceeded to remove the water, and since the pumping had continued after the barrel was emptied, the precipitation of air through the pores of the wood occurred. This experiment motivated Guericke to a new one: the manufacture of a copper sphere to which a pump could be attached, this time omitting the water and pumping the air directly. When he had apparently extracted all the air, the sphere suddenly deformed (suffered a compression effect) due to atmospheric pressure, thus varying the conditions he was creating new situations that allowed him to account for the vacuum. (Quintanilla & Camacho, 2008). I suggest reading the article to understand the adapted methodological proposal and reasonably select the learning activities indicated in Table 1.4.

1.8 Some Final Thoughts

Current international trends in research and innovation on teaching, learning, assessment, and the promotion of cognitive-linguistic skills show that just as students come to science classes with personal ideas about concepts and phenomena, specialized or non-specialized science teachers also develop their own conceptions about science, its teaching, assessment, and learning. During pre- and in-service training, these views are rarely considered and, consequently, teachers are not prepared to assume critical points of view towards scholarly knowledge or formal scientific knowledge, let alone towards their teaching performance, which would be possible if during professional development processes there were permanent environments and conditions for reflection, social interaction, and regulation of learning in a continuous and systematic way, favoring the communication of science in intellectually challenging contexts. Where, as I have argued in this chapter, language, emotions, values, each person's culture, and theoretical thinking have

Table 1.3 Guidelines for teachers to promote STC in students during different moments of the class

Stage	Activities promoted by the teacher	Questions guiding	Aims / objectives
Initial	Identification of scientific problems and communication of meanings.	What theoretical model do I want to teach? What do I want to ask? Who will learn? What planes of thought will I privilege?	Identify a "scientific problem" (concept-idea-problem-question). Select the typology or dimension of the problem (conceptual, procedural, attitudinal). Identify the underlying scientific theory Discriminate the level at which this problematic content is taught and the assumptions of the students/addressees. Identify the "developmental plane" in which the problem is initially formulated (instrumental, personal, communicative).
Intermediate	Problematization and identification of categories	What CPC will I promote? How will I work with my students? How am I going to teach them to identify the planes? What examples do I find most interesting?	Link the type of problem with a specific competency to be developed. Communicate to the students (or agree with them) the type of scientific competence and suggestion for solving the problem that has been stated. Teach students to identify the plane of analysis through which the scientific problem can be "mobilized". Identify with the students the theoretical framework of the problem, the procedural framework and the resources that make it possible to solve the problem (algorithmic and heuristic).
Final	Evaluation of the experience with students	What reflections did the confrontation with the problem enhance? In what planes of development did we situate it? What were the criteria to evaluate the scientific problem and how to face it? How did we identify them? What were the main difficulties of the analysis, how did we identify and overcome them? What scientific competences did we develop/learn?	

Table 1.4 Directions to promote scientific competences from a selected historical episode: *The vacuum pump* (Quintanilla & Camacho, 2008)

Identificación de problemas científicos		
Ejemplo		¿Cuáles son las sustancias que componen el aire?
1.1.1. Seleccionar tipo de conocimiento científico utilizando la historia de la ciencia como estrategia de promoción de aprendizaje competencial	CONCEPTUAL	Combustión, gases, elemento, compuesto y mezcla. Teorías disponibles en la época
	PROCEDIMENTAL	Uso de la bomba de vacío y otros instrumentos científicos en el contexto del episodio histórico.
	ACTITUDINAL	Acuerdos, pactos metodológicos, juicios, valores en disputa y discusiones de los químicos y científicos/as de la época.
2. Identificar la teoría científica que subyace (¿qué modelo teórico se quiere enseñar?)	Cambio químico. Teoría del flogisto de Sthal. Teoría de la combustión de Lavoisier. Concepto de elemento de Boyle. Estudio de los gases en el siglo. XVIII.	
3. Proponer preguntas interesantes vinculadas con la noción científica y el episodio histórico estudiado. (Ver Quintanilla & Camacho, 2008) e identificar planos del pensamiento en cada una de ellas y la orientación al estudiantado en términos científicos (pensamiento, lenguaje, experiencia)	1. De acuerdo con el episodio histórico estudiado ¿Cómo interpretaban Priestley y Lavoisier el fenómeno de la producción de un nuevo aire? 2. ¿Qué criterios utilizó Priestley para hablar de aire desflogistisado? 3. ¿Qué prácticas experimentales utilizarías para dar cuenta del “nuevo aire” en la bomba que utilizó Priestley o la de Lavoisier? 4. ¿Hubo alguna incidencia de la propuesta de Scheele, en la discusión entre Lavoisier y Priestley, qué crees y por qué? 5. ¿Crees que si Boyle hubiese trabajado en la misma situación, en la misma época y con la bomba que construyó, hubiera concluido algo similar a Priestley o Lavoisier? 6. ¿Qué piensas acerca de que la nacionalidad puede influir en las decisiones científicas? (Priestley, inglés; Lavoisier francés). 7. ¿Cómo definirías el oxígeno y el aire desflogistisado? 8. ¿Cómo relacionas el problema de la descomposición del aire con situaciones cotidianas?	
Problematizar competencialmente la actividad científica escolar		
Argumentación	Los químicos ingleses estaban equivocados. No existía aire desflogisticado, sino oxígeno.	
Explicación	Lavoisier vio oxígeno donde Priestley había visto aire desflogistisado.	
Descripción	¿Cuáles eran las ideas de Priestley y de Lavoisier acerca de la descomposición del aire?	
Justificación	¿Por qué Priestley habla de aire desflogisticado y Lavoisier de oxígeno?	
Explicación	¿Cómo explicas las ideas de Priestley o de Lavoisier acerca de la descomposición del aire?	

(continued)

Table 1.4 (continued)

Descripción	¿Cuáles fueron los recursos (conceptuales e instrumentales); los procedimientos y las estrategias que permitieron a Priestley y Lavoisier estudiar el aire?
Evaluación de la experiencia con los y las estudiantes	
¿Qué reflexiones hemos aprendidos de este episodio histórico? ¿Cómo se construye el conocimiento científico? ¿En qué planos de desarrollo lo situamos? ¿Cuáles fueron los criterios para evaluar el problema científico y cómo enfrentamos el desafío de aprenderlo? ¿Cuáles fueron las principales dificultades de análisis? ¿Cómo las identificamos y las superamos? ¿Qué competencias científicas desarrollamos y aprendimos? ¿Qué valor tiene la historia de la ciencia para aprender química?	

relevant importance. In this line of thought, recent research emphasizes the relationship between metacognition and learning to teach for the achievement of higher-level scientific thinking competencies, as it is argued that metacognition is central to promoting appropriate changes in teacher development, not only in relation to their ideas about teaching and learning but also about the content of the discipline, their teaching skills, and the basic epistemological foundations they must master and which must be consistent with their orientations and classroom practices that promote the development of such scientific competencies in their students, particularly today in a disturbed, convulsive, and uncertain world where learning science is also a right for all free-thinking citizens.

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Chapter 2
Discursive Interaction and Construction of Science in the Classroom

Antonia Candela

2.1 Introduction and Theoretical Considerations

In this chapter, we aim to study several scientific knowledge co-construction processes in the natural context of the school classroom. Sociocultural orientation studies, with increasingly greater consensus in the field of educational research, argue that meaningful learning not only depends on the subjects' prior ideas and their spontaneous evolution, as psychogenetic research has shown, but on the interactive sociocultural context in which it occurs (Bruner, 1984; Vygotsky, 1987; Lave, 2011). Therefore, to understand how science is taught and learned in the classroom, it is necessary to study the processes of constructing a shared understanding (Edwards & Mercer, 1988) through the discourses between teachers and students that are characteristic of the school situation in classrooms. Growing interest in the social contexts of content construction makes language—as the medium through which knowledge is publicly manifested—increasingly important for educational research. Thus, unveiling the social, contextualized, pragmatic, and pedagogical form of thought that can be gained by analyzing discourse in a school setting is of interest. To achieve this, it is also essential to adopt the theoretical perspective of ethnography, which, from a qualitative and interpretive position, aims to understand the logic of the actors (teachers and students, in this case) in the interaction process, thus avoiding an evaluative stance (Lave, 2011).

Science —like any other way of describing reality to make it socially intelligible— implies communicating within a set of assumptions and shared knowledge in a community (Phillips, 1985; Latour & Woolgar, 1986; Longino, 1990;

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Gilbert & Mulkay, 1984; Potter & Mulkay, 1985). Likewise, schools are social spaces where there are certain, particular forms of communication and where discourse has a distinguishable structure and specific language (Bruner, 1986; Candela, 1998; Gumpertz, 1982). This language is an important part of constructing science, and it needs to be communicated to students, which is why it is studied as an important factor in learning (Sutton, 1992; Lemke, 1990).

In this line of reflection, I study various characteristics of the discursive construction of science in social interaction between teachers and students in the classroom, considering speech as situated action in a specific context, as established, among other perspectives, by discursive psychology (Edwards & Potter, 1992). This process of socio-cultural communication—in which shared meanings are constructed along with parallel and alternative versions of the content—constitutes my object of study, because I assume this process shows the characteristics of co-constructed scientific knowledge, which also allows for distinguishing between student participation and their process of appropriating school knowledge. Several disciplinary perspectives converge in the study of these socio-cultural interaction processes and contribute to this research. This is the case of developments in anthropology that explore the relationship between culture, language, and cognition and consider cognitive and linguistic development as a form of socialization and cultural learning (Lave, 1988; Ochs & Schieffelin, 1984). Language is conceived as cultural mediation for thought and action expressed in everyday practices (Edwards & Mercer, 1988; Scribner & Cole, 1981). Within the Vygotskian conception, discourse and communication also play a central role in constructing scientific knowledge, and the socio-cultural nature of this construction process is assumed (Vygotsky, 1987).

Argumentation and consensus, as complementary parts of what has been called conflictive speech (Grimshaw, 1990), allow for collecting those moments when participants' alternative versions and discursive competence (Gumpertz, 1982) to defend and negotiate them stand out more clearly. Therefore, analyzing the discursive resources that students use in conflict situations is of particular interest. However, students' contributions cannot be understood without placing them in the context of discursive interaction among peers and, especially, with the teacher. This implies the need to study the communication process, which I do by analyzing discursive interventions between the teacher and the students. Understanding speech as a social action that constructs realities, identities, and cognition itself (Edwards & Potter, 1992), I study the process of constructing science within the framework of a school—which is an institutionalized, intentional, and asymmetric situation—through discursive interaction between the teacher and the students. The detailed analysis of the sequence of turns provided by conversational analysis (Sacks et al., 1974; Atkinson & Heritage, 1984) makes it possible to reveal the social organization in the context and the relationship between the actors and the content in a very precise way. Several characteristics of this construction process that I have researched are listed below (Candela, 1999):

(a) The discursive procedures through which a fact is legitimized in the classroom as a scientific fact and the role that is discursively assigned to "evidence" (Candela, 2002)
(b) The argumentative structure of classroom discourse and the way students contribute to this argumentative construction of content and interactive context (Candela, 1991 and 1996)
(c) The orientation of school discourse towards constructing consensus despite its argumentative nature (Candela, 1995)
(d) The discursive processes through which the local asymmetry of power in the classroom is reconstructed and modified step by step. (Candela, 1997a, b).

In this chapter, I will only show examples of the first two characteristics.

The empirical research was carried out in several public, primary-school classrooms in a marginal area of Mexico City and in rural community schools. I also include an example of interaction between a group of university-level, physics students because it is relevant to the argument presented in this chapter. Science classes for fifth-grade primary school and group work sessions for solving third-semester, physics homework problems were observed. Ethnographic records, video, and audio recordings were taken of each class as well as audio recordings of group study sessions. Later, the transcriptions of these recordings with references to the video were used, especially in situations where a greater richness was found in the discursive interaction between teachers and students, in the first case, and between physics students, in the second.

2.2 Objectivity of Evidence?

Based on the importance of "empirical evidence" in science for establishing scientific facts as the seemingly most objective factors, this section analyzes the discursive procedures for establishing the legitimacy of various sources of knowledge and how scientific facts and their relationship with "evidence" are presented. Scientific facts are the descriptions that discourse participants grant an impersonal character and that become real due to their apparent objectivity. Especially in the field of science, the scientific fact is a discursive phenomenon that is produced with a type of apparent neutrality as being independent from the subjects and the social conditions of production, and therefore, it is established as truth (Gilbert & Mulkay, 1984; Potter, 1996). The impersonal character of descriptions of scientific facts has been studied, mainly, in the texts and public presentations of scientists (Gilbert & Mulkay, 1984).

To study how the character of "empirical evidence" is discursively established and what its claimed objectivity is, I analyze the discursive construction of what "is seen" in experimental activities in science classes. This type of analysis is shown in the following example of an experiment carried out to observe how water with calcium oxide (commonly known as lime) becomes cloudy from combustion when it comes into contact with carbon dioxide:

Excerpt 1: “I Can’t See It”

910 **Student 1:** **It’s not burning anymore.** *((referring to the cotton))*
911 **Teacher:** **Ah, yes, it stopped burning ° (.) They should put easier activities in the**
912 **books for people who don’t**
913 **know how to understand (.2) things.**
914 * **Students:** **He he he**
915 * **Teacher:** **We should invent a person who makes fires for**
916 * **a living.** *((As the teacher says this, the teacher pours*
917 * *lime water into two glasses, one with burnt cotton and another with*
918 * *cotton that has not been burnt. Many of the children make comments*
919 * *among themselves in a joking tone…))*
920 * **Teacher:** **And now:: (.2) let’s look at the difference**
921 **between the two waters with lime (.) okay? (.3) THIS IS**
922 **so you won’t say that the cotton was**
923 **discolored (.) that the cotton (.) made (.)**
924 **the water with lime turn milky. Rather, it was**
925 **exclusively the combustion (.2) on this side. (.5)**
927 => **Student 2:** I CAN’T SEE.
928 **Students:** **He he**
929 **Teacher:** **On this side (.) the lime water is almost transparent,**
930 **Javier. (.2) Do you see?**
931=> **Student 2:** **No.**
932 **Teacher:** **And on this side, it looks whiter (.2) despite**
933 **hav[ing pieces of burnt paper in it, (.2) and we’re going to**…
934=>* **Student 1:** **[I don’t see it, teacher.**
935 * *((There are other incomprehensible comments, but the teacher*
936 * *doesn't stop talking.))*
937 * **Teacher:** **Come up where you can see them, (.2) okay?**
938 * **Let’s put (.2) a little more water with**
939 * **lime (.4) in this one. There we go. (.) Let’s go over here.**
940 * **(.2) Did you all see? (.) In this one, the water looks a little > whiter<**
941 * **than in this one. (.2) In this one, it still looks**
942 * **transparent. (.5)**
943 * *(There are many comments from the children but in very low*
944 * *voices.)*
945 * **Teacher:** **Look at both of them. (.) Did you already see both?**

946 =>* Student 1: No.
947 * Teacher: Yes, look at this one. It looks whiter, and this one still
948 * looks almost transparent (.) like how it looked when
949 * we first made it. (.) Right, Maricela? (.2) ^SIMON (.) BE QUIET
950 * WILL YOU. Please. (.) Did you see? (.) On this
951 * side, (.) the water looks whiter, milkier
952 * than on this side. On this side, it's completely
953 * transparent like when we started. (.3) Did you see?
954 * (.5) This one i:s clearer, right?
955 =>* Student 3: No. *((Many children speak but in low voices that are incomprehensible.))*

In this excerpt, "what is seen" by the teacher is never "seen" by the students, despite the multiple "clues," guidance, and even descriptions of "what is seen" provided by the teacher. Not only does the teacher propose what is supposed to be seen at the beginning of the experiment, but he also repeats what he believes is seen on several occasions. However, despite the teacher's authority in the classroom, the students repeatedly deny that they see what he says can be seen. Based on this excerpt, it can be deduced that "empirical evidence" does not seem to be an objective fact. People interpret what they see based on their preconceptions, and whether or not certain aspects of reality can be seen depends on these preconceptions. Therefore, in the classroom, far from having an objective and unique character, "evidence" appears as a social construction that is developed in the interaction between the students and the teacher, at times in a process of discursive enrichment of "what is seen" and, at other times, through opposing viewpoints of "what is seen" or "what is felt." The teacher's authority or the words written in the textbook are not enough for students to "see" what is supposed to be seen.

In the studies that were conducted, I have found that "evidence" is not the only legitimate source of knowledge that the teacher establishes in the classroom (Candela, 1999 and 2002). Alternative ways of legitimizing knowledge also appear, such as analogy as a way of showing the validity of an explanation in the face of a difficult-to-access fact; majority opinion; the authority of "those who know more" (parents, the book, specialists); reasoning (logical argumentation); and consensus in the group. The teachers who were studied seem to base their version of scientific facts on a reference to the textbook, that is, on what the scientific consensus in the classroom would be or what the textually legitimized source of school knowledge would be. All these forms of legitimation appear in debate with what is considered "evidence" in the process of constructing the scientific fact.

For children, the criteria of truth and the legitimate sources of knowledge to define facts as "what is right" vary. Sometimes, the teacher is viewed as the possessor of truth, but not always. On occasion, they demand consensus as a criterion of truth. But there are situations in which majority opinion—and even the version backed by the authority of the teacher or the textbook—is questioned based on sources of knowledge established as "empirical." These discursive mechanisms that are used in the classroom to validate a fact as scientific have significant similarities with the mechanisms that scientists use to legitimize knowledge: analogy, argumentation, consensus among the scientific community, or the judgment of "experts" (Elkana, 1983).

2.3 Argumentative Construction of Science

Science is not only content; it is also a procedure, a way of structuring ideas based on a logic that, for Marcelo Pera (1994), is a dialectical logic and, therefore, relates to the paradigmatic structure, which is unlike other ways of organizing reality, such as narrative (Bruner, 1986).

Assuming that the discourse of science has a rhetorical or argumentative organization (Billig, 1987), it is also of interest to analyze the argumentative organization and rhetorical characteristics of school discourse on scientific topics. More structurally, this rhetorical analysis is based on the idea that science is not a mirror of nature or an arbitrary cultural construct; rather, its conceptualizations are not accepted unless they persuade a community that counterargues based on theoretical, technical factors and specific strategies, making rhetoric a constitutive element (Pera, 1994).

Based on the notion that a scientist is passionate about explaining (Einstein), a good scientist should have a highly developed argumentative capacity. In an argument, interventions are linked through confrontation, and therefore, what someone says is connected, in a debate, to what another person expresses (Billig, 1987). Below, I present an excerpt that shows how a group of physics students at a Mexican university (UNAM) proceed to solve homework problems in the study group they formed to support each other and work collectively (Candela, 2018).

Excerpt 2: Lola's Doubts

Lola asks Pedro a question, pointing out the problem she solved for homework. He explains how he solved it. Then, Lola asks Daniel if he did it the same way that Pedro did. The three of them look at the class notes in Lola's notebook and talk about the problem, discussing the differences between Daniel and Pedro's procedure and Lola's procedure as well as the reasons why they did it the way they did. Lola seems partly convinced because she corrects a sign and makes changes to her solution while the other two watch her. Then, she decides to erase everything and do it again because she doesn't get the expected result (zero). Daniel and Pedro return to their homework. When Lola finishes and gets the result of zero, she says: "Now I believe you."

This interaction between the three students shows significant elements of the study group's work practice in relation to the training physicists receive in argumentation. First, it shows that each student makes an individual effort to solve the problem. Second, it seems evident that students have the ability to judge their own results based on general criteria that allow them to evaluate the obtained solution as "possible" (it should be zero). This requires having an idea of the physical process which defines that the solution "must have certain characteristics" more so than a mathematical one. Third, in this sequence as in others, there is a clear practice of corroborating results with peers to verify if their own results are adequate, especially when there are doubts, as in Lola's case. Fourth, a critical attitude is upheld towards the answers provided by other students, even if several classmates provide the same answers, and arguments are made about the differences in procedures, using all available resources (such as class notes). Thus, even if a student is not sure about their procedure or solution, and even if several classmates provide a different solution, this is not enough to accept the alternative answer provided by others until the first student verifies it. A fifth interesting element in this sequence is the coherence the three students seem to seek between class notes and the procedure that leads to the problem's solution, but they do this by making arguments, because there is no direct relationship between the two, as shown by the way the three students try to interpret the meaning and relationship. And finally, it is noteworthy that Lola only accepts her classmates' viewpoint after repeatedly performing the operations, erasing everything to start from the beginning until she reaches the expected result. This situation exemplifies the degree of autonomy commonly found among students, even if they receive help from their peers, and the role that argumentation has among them as a guiding procedure; however, at this level, it does not replace mathematical verification.

Next, I will show an example of argumentative interaction that takes place during an activity in a fifth-grade elementary school group in which students have to list various materials in descending order of densities. With the analysis of this excerpt, I will exemplify the information about the details of the interaction and the turn-by-turn negotiation of knowledge construction that conversational analysis allows.

Excerpt 3: "Lead or Steel?"

147 Student 26: The lead.

148 Teacher: ^Is lead heavier? (.2)

149 Why:?

150 Student 1: Oh, no::

151 Student 26: Because it has more matter::?

152 Teacher: [Okay:::?

153 Student 2: [More matter.

154 Student 29: No:: (.) Lead hardly weighs anything, (.) teacher.

155 Teacher: >Lead doesn't weigh mu:ch.<

156 ***((The teacher says this in a confirming tone, looking at Student 26.))***

158 Students: Ha ha ha ha ha::: *((looking at Student 26))*

159 ** **Student 4: NEITHER DOES STEEL.**

160 ** **Student 19: I said copper.**

161 ** **Student 1: °Co[pper doesn't weigh (.) much either, teacher. °**

162 ** **Student 19: [I said copper.**

163 ** **Teacher: ^STEEL DOESN'T WEIGH MUCH EITHER::? (.2)**

164 ** **Student 16: /Yes, it does. (.2)**
165 ** **Student 4: /Not much.**
166 ** *((Many of the children comment among themselves.))*
167 ** **Teacher: LET'S SEE (.) THEN.(.) <WHICH ONE IS GOING TO BE HEAVIER>?**
168 ** **Student 19: The copper::?**
169 ** **Student 1: The [steel.**
170 ** **Student 2: [The steel.**
171 ** **Teacher: THE STEEL OR THE COPPER?**
172** **Students: THE STEEL.** *((most of them in chorus))*
173** **Student 1: /Why::? (.3)**

At the beginning of this excerpt, Student 26 proposes lead as the heaviest material, and in response, the teacher asks for a justification **(^Is lead heavier:? (.2) Why:?")**. Two students give different answers. While the first student seems to retract, Student 26 makes an argument in favor of his proposal of lead ("**Because it has more matter::?**"). The same situation is repeated with the teacher's questioning ("Okay?") and the two answers: one confirming the argument in favor of lead and the other stating that lead hardly weighs anything.

Without pause, the teacher repeats the child's answer, reformulating it (changing **"hardly weighs"** to **"does not weigh mu::ch"**). The repetition of an assertion, without pause, is a way of accepting the content of the previous turn established in conversational analysis (Pomerantz, 1984). The teacher's explicit statement against lead does not keep Student 4 from using the same argument that Student 29 and the teacher had used to reject lead **(">Lead does not weigh mu::ch<")**, now directing it against steel **("NEITHER DOES STEEL")**. Student 4's statement seems to openly oppose the teacher in the form of an unsolicited counterargument to her statement.

After some interventions in favor and against copper as a third option, the teacher questions Student 4's claim that steel isn't heavy using a very loud voice **("STEEL DOESN'T WEIGH MUCH EITHER::?")**. Repeating a statement in a questioning tone is a form of rejection (Pomerantz, 1984). Prompted by this questioning, the teacher seems to focus her involvement on the debate between steel and lead, trying to ensure that steel is not discarded. The students' following statements are different ways of adjusting in response to the teacher's involvement. While Student 16 supports the teacher by stating that steel is heavy, Student 4 softens the position he took when he said, "**NEITHER DOES STEEL**," but he does not relinquish it (changing to **"/Not much"**).

An interesting aspect from the viewpoint of argumentation is that, from the point when Student 4 openly rejects the teacher's position by saying "**NEITHER DOES STEEL**," the noise in the classroom (indicated by the annotation) increases significantly. Many children make comments among themselves at that moment in what seems to be an escalation of the debate. The teacher's discursive resources, which had the intention of guiding students towards naming a specific order of materials, seem to lead the discourse to a confrontation between versions rather than bringing it closer to a consensus.

In this context, the teacher uses a loud voice to ask for a summary, posing the initial question: **“LET’S SEE (.) THEN (.) <WHICH ONE IS GOING TO BE HEAVIER>?”** This question, after the teacher argues against lead and questions the argument against steel, seems to influence the group to eliminate lead as an option for the heaviest material, and the answers only mention copper or steel. The teacher asks them to choose between these two materials, and the students state “steel” in chorus, in what seems to be, at last, a resolution of the debate with a consensus in favor of steel.

However, a child intervenes immediately after the collective response, asking: **“/ Why::?”** This question, in the form of a demand for justification, breaks what seemed to be a general agreement; that is, it reorients the discourse towards argumentation. According to the preferential structure, this intervention acts as a rejection of the previous turn. It is interesting that, despite the school hierarchy and the power asymmetry in the classroom, in this case, the student not only asks the question but also demands a convincing argument in the same way the teacher did near the beginning of the extract when she asked **“Why::?”** to show disagreement with an individual version. He seems to appropriate the discursive resource—which the teacher first used to demand an explanation and reject the previous version—now using it against the collective version in favor of steel.

In several studies (Candela, 1991, 1996 and 1997a), I have found that argumentation between alternative versions frequently appears in classrooms, and this contributes to the creation of scientific attitudes. The following are some examples of the ways argumentation appears: (a) The teacher promotes arguments by frequently asking “why?” (b) Students also demand convincing arguments. (“Why does iron sink even if it’s small, and a log doesn’t even if it weighs a lot? I’ve seen it.”) (c) Students argue, even when they are not asked to. (d) The teacher also argues and justifies her version, thus encouraging argumentative participation from students.

In other analyses of science-class transcripts that, due to limited space, cannot be presented here (Candela, 1999), the dialectical relationship between argumentation and the construction of consensus based on alternative versions that teachers and students hold about scientific knowledge is also discussed. The classroom is a space for building agreements, and the procedures for achieving them are part of the job of teaching. Students demand it, and teachers negotiate with it. In order to educate, one must know how to convince.

2.4 Conclusions

The analysis of discursive interaction in science classes in Mexican primary schools shows the richness of versions of scientific facts constructed in interaction. Students contribute significantly to this richness with their questions, reasoning, and alternative versions that make science in the classroom a living and developing science rather than a finished and unquestionable science. Students' participation appears when they share meanings of schoolwork and actively debate about different versions of the scientific content, appropriating the discursive resources that teachers have put into play for this purpose, with clear communicative competence.

In the case of peer discourse, shown with the example of university physics students, it is apparent that they have already appropriated resources such as critical thinking, autonomous reasoning, and argumentation about the theory that explains physical phenomena. Moreover, they make arguments about the interpretation of this theory as it relates to a specific problem as well as the application of mathematical resources, in accordance with the theory, to solve the problem.

As for primary school students, it seems that if the discourse leans towards an option they agree on, they can accept the teacher's guidance towards constructing a consensus, but otherwise, they can guide themselves towards upholding the argumentative context, even interrupting the structure of social participation that the teacher is trying to lead. Therefore, they do not assume themselves to be those who "do not know," at least not in all cases. They construct an identity as those who sometimes know the content and, therefore, negotiate it with the teachers. We see the students as competent communicators, as subjects who are willing to defend their viewpoints and who are also knowledgeable about much of the content addressed in the class.

A specific aspect that can be derived from this research is the importance of experimentation in the classroom as a space that opens up the possibility to construct alternative facts. Yet, the studies that were carried out reveal that the debate about the various explanatory alternatives of natural phenomena is even more important than experimentation. This is true whether these debates result from experiments carried out in the classroom or are part of students' extracurricular knowledge.

Discussing the same phenomenon in different contexts can lead to the development of important scientific attitudes. It is advisable to promote the expression of all possible versions of a "fact" in order to develop students' explanatory capacity. Comparing different versions contributes to the development of students' argumentative skills, which fosters an important approach toward constructing scientific knowledge. In all these case studies, there are significant examples of students imitating and appropriating the resources that teachers put into play (as opposed to improvising them or discovering them autonomously), which seems to lead them to processes of scientific knowledge construction that have significant similarities with the social processes of construction within science.

It is necessary to consider research on constructing scientific knowledge in the classroom as the bridge that will inform us about what can be modified in the teaching of science; this should be based on what is done in the classroom and, therefore, what teachers are capable of implementing by employing the training and resources that can be developed in their professional practice and in relation to the comprehensive development needs that students have as culturally diverse social subjects. To do so, it is fundamentally relevant to understand and consider what students know or what they can do at a communicative level, as well as the characteristics of the sociocultural processes of knowledge construction and, in particular, those that occur in a social institution such as the school. These aspects, which are more closely related to local classroom conditions, are in tension with the current trend to develop "competencies" that are imprecise or frequently defined outside of the schools and based on the developmental needs of the current economic system.

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Chapter 3
Scientific, Didactical and Analogical Models in Science Teaching

Agustín Adúriz-Bravo

3.1 Introduction

This chapter presents theoretical ideas and practical proposals that can be inscribed in one of the lines of research and innovation of my group GEHyD at the Universidad de Buenos Aires (Argentina), the line dealing with the nature and function of what I call "school scientific models". Some of the results I have obtained in this line were reported in presentations at various biennial editions of the *REF* (*Reunión Nacional de Educación en Física*: National Meeting on Physics Education, in Argentina)[1] and in scientific publications in different formats (e.g., Galagovsky & Adúriz-Bravo, 2001; Adúriz-Bravo & Galagovsky, 2003; Adúriz-Bravo, 2009, 2011, 2012, 2013, 2015b, 2017, 2022; Adúriz-Bravo & Izquierdo-Aymerich, 2009; Adúriz-Bravo et al., 2014; Ariza et al., 2016; Díaz-Guevara et al., 2019). In all these publications, I present -with a number of collaborators from Argentina, Spain and Colombia- theoretically-grounded reflections from didactics of science (i.e., science education understood as a scientific discipline) about the different roles played by representations, models, analogies, and metaphors in the construction and communication of school scientific knowledge in (formal) science teaching processes within compulsory education.

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[1] Adúriz-Bravo and Galagovsky (1997) and Adúriz-Bravo et al. (1997), oral presentations published in the proceedings of *REF X*; Adúriz-Bravo and Morales (2002), extended version of a presentation at *REF XII*; Adúriz-Bravo and Bonan (2003), poster presentation at *REF XIII*; Adúriz-Bravo (2015a), semi-plenary lecture at *REF XIX*; Adúriz-Bravo (2019), plenary lecture at REF XXI; and Adúriz-Bravo (2021b), plenary lecture at *REF XXII*.

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I consider it important to relate this chapter to some of the group's previous academic developments, as this allows me to place the readers in the perspective from which I am formulating classroom recommendations with the aid of my notion of *didactical guidelines*. Writing this chapter supposes a challenge for me as author, since it demands an interesting and necessary -but rather difficult- metadiscursive exercise of reviewing and synthesizing my previous theoretical formulations. It is my purpose here to make explicit some of the assumptions underlying my work of research and innovation in didactics of science in the area of models and modeling.

It is of the utmost importance for this chapter to acknowledge that the current literature on models and modeling in didactics of science is extremely extensive and diverse; therefore, it seems advisable, in the first place, to position myself within a distinct research perspective that conveys the foci of my professional interests, and subsequently select some pieces of the vast intellectual production available that respond to that perspective according to a set of theoretical criteria. Taking this into account, in this chapter I retrieve the categories of *scientific model*, *didactical model*, and *analogical model*, widely used in our discipline for the last four decades (see Duit, 1991; Gilbert, 1993; Gilbert & Boulter, 2000; Chamizo, 2010; Gouvea & Passmore, 2017).

Some authors use the expression of "didactical model" (or "teaching" or "instructional" model) to refer to representations, analogies or other *mediating* resources between the (curriculum) content to be learned and (students') common-sense knowledge. In this sense, the concept of didactical model constitutes a fundamental instrument to address key problems of science teaching at the different educational levels, since it contributes to establishing links between theoretical analyses and teaching practices.

I inscribe myself in the so-called "cognitive model of school science" (Izquierdo-Aymerich et al., 1999; Izquierdo-Aymerich & Adúriz-Bravo, 2003; Adúriz-Bravo & Izquierdo-Aymerich, 2009), from which I define didactical models as the *didactical transpositions* of scientific models, i.e., models prescribed to be taught in the curriculum of (natural) science in the different educational levels (from kindergarten to university). In this sense, I will here speak of didactical models (or "school scientific models", or "school theoretical models") to refer to the scientific content effectively taught, even at the university level (Bonan, 2002).

I also talk here about analogical models, understanding that these do not share content with their analogue counterpart (the *analogandum*, the didactical model to be analogically represented for teaching). Rather, they are located in an external semantic (or conceptual) field, and serve as a vehicle to link and anchor the highly complex and abstract meanings of school scientific content to the less complex and more concrete content available in the cognitive structures of students. A well-known example of this is the "plum pudding" analogy for Thomson's atomic model (Hentschel, 2009). These *expressive* conceptual objects allow for more meaningful representations of the model's content and permit both its comprehension and its transfer to other fields of problems.

The reflections I make in this chapter are inscribed in a broader theoretical view of science teaching that argues for the importance of "talking and writing science"

(Lemke, 1990; Sanmartí, 2003). This view places special emphasis on school scientific *argumentation* as a central competence for science teaching. In this matrix of ideas, the use of a scientific model to structure an argument (*so that it is able to explain*) would ensure the logical quality of the "ascent" from data to conclusions. The link that I am postulating between arguments and models goes hand in hand with the definition of argumentation to which we adhere in my research group, which conceives it as a situated social activity aimed at validating or refuting claims, and which consists of presenting plausible *supporting evidence* taking into account the receiver of the argument and the purpose for which it is issued (Sanmartí, 2003). In order to argue, it is necessary to choose between different theoretical models that can provide *rival explanations*, and to examine the *rational criteria* that allow evaluating the chosen option as more appropriate than the others (Sanmartí, 2003).

In this definition of argumentation, different theoretical elements appear: a socially situated "act of speech", the audience, the purpose of convincing sustained by the producer of the argument, and the "path of reasoning" that uses the selected model to attain conclusions. In summary, argumentation, seen as a central *cognitive-linguistic competence* for scientific activity (whether of scientists or of students), would "weld" four components: *rhetorical*, *pragmatic*, *theoretical*, and *logic*. These components refer to the fact that the generated argument seeks to convince the intended audience, is contextualized in a specific praxis, points at a theoretical model that serves as a reference for the explanatory process, and is structured through a complex and elaborate syntactic architecture (Adúriz-Bravo & Revel Chion, 2014).

From the perspective to which I adhere, then, exercise of the argumentative competence results in the production of *explanatory texts*. This type of texts supposes a great cognitive challenge to students, since it requires them to analyze and identify the existing relationships between the theoretical ideas that "define" the scientific model (Giere, 1988) that is used to explain and the *evidence* obtained via different elaborate mechanisms (observation, experimentation, reasoning, simulation…). I adhere to the idea of an *argumentative nature of science*: from a distinctive epistemological position, I consider argumentation as one of the central *epistemic practices* of science (Izquierdo-Aymerich & Adúriz-Bravo, 2003). This practice is developed within knowledge (or practice) communities holding their own rules and values, with the purpose of *constructing meaning* about the natural world through the use of theoretical models.

On the other hand, the recovery in this chapter of analogies as a central didactical (i.e., instructional) tool is not at all new (see Treagust et al., 1998), but here I examine such a tool intending to exploit its potential more deeply by means of the inclusion of metacognitive vigilance and concepts from the philosophy of science as important ingredients for science teaching. A proposal that I take as a strong reference due to its usefulness for science classes is the sequence of steps that has been called "analogical didactical model" or "analogical model for science teaching" (Galagovsky & Adúriz-Bravo, 2001; Adúriz-Bravo & Galagovsky, 2003).

3.2 Theoretical Foundations

In this section, I outline a number of theoretical perspectives coming from the philosophy of science and from didactics of science that have allowed me to explore some of the complexities of the field of scientific representations, within which models and analogies are situated. The intended purpose here is to theoretically support my proposal for the formulation of didactical guidelines on the use of analogies in the science classes of the different educational levels.

3.2.1 The Model-Based View of Science

The epistemological model that serves as a reference for the didactical innovations produced by my group comes from the so-called *semantic* and *cognitive* philosophy of science of the last quarter of the twentieth century. Among the contributions of this school, I select what is known as the *model-based view of science*, especially as it is developed by the recently deceased American philosopher Ronald Giere (1988, 2006).

Summarily, this current in recent and contemporary philosophy of science can be characterized by its proposal of *scientific models* as the structural and functional units for metatheoretical analysis. Models thus displace theories, which were the classically chosen units (for example, by logical positivism and the received view). Giere speaks of “theoretical models” as non-linguistic, abstract entities that connect analogically with reality (due to their degree of *similarity*), thus accounting for only some *selected* aspects of the represented systems (Giere, 1988). Models as imagistic entities have the property of “satisfying” the formal propositions that define them in different languages. The assumption that there is a partial and pragmatic fit between pieces of reality (facts of the world) and models, mediated by theoretical choices in each particular theoretical problem to be solved, is known as *perspectival* realism (Giere, 1988, 2006).

In this framework of ideas, models can be understood as idealized representations of real systems that include general aspects (characteristics and descriptions) and specific aspects (structure and function) “captured” from those systems (Adúriz-Bravo et al., 2014). All these aspects are organized on the basis of sets of strongly *hypothetical* propositions. A model acquires validity insofar it allows the description, analysis, and interpretation of the purportedly modelled system.

From a semantic point of view, models are a particularly elaborate class of abstract representations of objects, systems, properties, phenomena, processes… A model is always a model *of something* (Adúriz-Bravo, 2022): it aims at capturing a piece of the world, and necessarily simplifies what it represents (i.e., re-presents, presents again in absence). Models seek to *understand* their surrogate objects through a very sophisticated use of the principles of the theoretical framework of which they are “carriers” (Adúriz-Bravo, 2011, 2012, 2013).

It can be stated that the relationship between the real world and theoretical models is one of similarity (Giere, 1988): a model is similar to the real system it intends to model in some *aspects* and *degrees*; it only represents some purposefully chosen entities and relationships of that system and idealizes and simplifies them to fit the theory (Adúriz-Bravo et al., 2014).

In this epistemological view to which I adhere, scientific theories can be seen as *families* of models that are linked by a strong affinity in their topics. According to the semantic philosophy of science, a model as an abstract, theoretical entity becomes "interpreted" in the real system for which it functions as an analogue. In this sense, any scientific theory contains, in addition to its formal core (the so-called *Kern*, in terms of the well-known German nomenclature of *structuralist* philosophy of science) of principles and laws, the set of its intended *applications* to reality and also a methodological "know-how". Those concrete applications of the theory (the scientific models *sensu stricto*) are analogical "displacements" of a more abstract, paradigmatic theoretical model to various realms of reality among which scientists find structural and functional similarities.

Giere's (1988, 2006) powerful formulation of what models are, which I have summarized here, also allows *considering analogical models as elaborate mediators* in this theoretical process of *explanation* of reality, and hence the value I find in this author's ideas for science teaching (Izquierdo-Aymerich & Adúriz-Bravo, 2021).

3.2.2 Analogical Reasoning in Science and in the Teaching of Science

Careful theoretical attention to the praxis of scientific language is a relatively recent endeavor in metatheoretical studies on science, which has allowed us to see the difficulties of the ambitious logical positivistic project of finding a *univocal and exact scientific language*, of formalized and universal nature. Nowadays, scientific language is thought of from categories provided by a diversity of disciplines, including pragmatics and rhetoric (Izquierdo-Aymerich, 2000, 2017). In this context, analogical reasoning is accorded a key role: scholars give enormous value *to the analogies and metaphors* that scientists use both to communicate and to *construct* knowledge.

For the context of school science, I adhere to Lemke's (1990) view that it is necessary to explicitly *teach* students to "talk and write" science, as this would be the means through which they can internalize, communicate, and apply specialized conceptual knowledge and know-how about natural phenomena in the various areas of school science. Analogical reasoning is an important *facilitating* tool in this process, as it allows the establishment of non-arbitrary relationships between the scientific models to be learned (mandated in the curriculum) and the established meanings that students possess in relation to scientific problems (Duit, 1991; Clement, 1993; Dagher, 1994).

Broadly understood, analogical reasoning is a search for non-superficial similarities between two "domains" of content. Analogies start at a domain that is known and familiar (the "source") and project this domain to a second one (the "target") that is new and requires explanation. The well-defined projections proposed by the analogy can be of structural, functional or semantic nature (Adúriz-Bravo & González Galli, 2021). There are numerous types of analogical "transport" (*metaphor* understood as an abstract mechanism) that have interest for science teaching; in previous publications, I have characterized the categories of analogical models, concrete analogues, and epitomes (see Adúriz-Bravo, 2005).

3.2.3 School Scientific Modeling

The cognitive model of school science, particularly developed by scholars of didactics of science at the Universitat Autònoma de Barcelona (Spain), argues that considering "school scientific activity" as an authentic modeling process would be a fruitful change in theoretical perspective for the actual practices of science teaching in the different educational levels (Izquierdo-Aymerich et al., 1999; Izquierdo-Aymerich, 2000; Izquierdo-Aymerich & Adúriz-Bravo, 2003). This characterization of school science as a model-based activity arises from the convergence of a number of research lines in didactics of science that highlight the roles played by language, models, interventions, self-regulation, contexts, purposes, and values in the science classrooms.

In this chapter, I understand school scientific activity as an articulated set of classroom practices intentionally designed by science teachers and aimed at establishing coherent relationships between doing, thinking, reasoning, arguing… *and also structuring, expressing, and applying knowledge*. This notion of school scientific activity requires a style of science teaching practices based on enquiry: "real" facts in the world that constitute a puzzle for students are transformed into *scientific facts* by giving coherent theoretical meaning to the interventions and languages used (Marchán-Carvajal & Sanmartí, 2015).

Authors such as Mercè Izquierdo-Aymerich (Izquierdo-Aymerich, 2004; Izquierdo-Aymerich & Adúriz-Bravo, 2003) consider that school scientific activity has as strong requirement to firmly connect the facts in the world with appropriate theoretical models so that they can be satisfactorily explained by students with different semiotic resources. These serve them to *argue* about the substantive relationships between facts and models through a careful use of *evidences*. Therefore, the design of the school scientific activity should select facts that make sense to students (and therefore can be turned into genuine "school science problems"), and then transform them, through the use of theoretical knowledge, into "paradigmatic facts" that will function as school theoretical models. The obtained (reconstructed facts functioning as) models will be subsequently applied by students to solve new problems with increasing degrees of autonomy.

In this sense, I adhere to a conception of a school science curriculum based on a small number of "irreducible" models -that is, the most essential models that constitute the "backbone" of the different natural sciences, representing the deepest conceptual structure of each scientific discipline (Adúriz-Bravo et al., 2001). I thus postulate the need for a didactical transposition that respects what I call the "structuring fields" of the natural sciences: the families of problems and models that are characteristic to them.

To achieve students' *re*-constructions (i.e., appropriations) of didactical models, this line of research suggests, as I have advanced, the theoretical construction of paradigmatic facts. These theory-laden facts would function as proto-theoretical models à la Giere; their production would be facilitated by analogical models, which allow for an initial, significant introduction of school theoretical school models along with the clear definition of their domains of application. Paradigmatic facts arise from a theoretical reading of a variety of *interventions* (observations, experiments, simulations, analogies…) typical of school scientific activity (Izquierdo-Aymerich et al., 1999).

This epistemic value of analogies in the reconstruction of models has been highlighted by numerous authors who, nevertheless, have pointed out some of the problems that arise when using them (see a review in Treagust et al., 1998). Acknowledgment of the reported problems has led researchers in my group to design and test various didactical strategies for using analogies (Galagovsky & Adúriz-Bravo, 2001; Adúriz-Bravo & Bonan, 2003; Adúriz-Bravo & Galagovsky, 2003; Adúriz-Bravo & González Galli, 2021) that have in common a metacognitive and self-regulatory approach that could be seen as "epistemological vigilance".

3.3 Theoretical Guidelines for Designing Didactical Units

Members of my research group along with various national and international collaborators have been carrying out, for the last two decades, a number of successive didactical interventions in classrooms of K-12 school science and of science teacher education. Such interventions cover a broad spectrum in terms of the educational levels, curriculum subjects, types of institutions, and even countries, where they were implemented. Through all those interventions we have tried to test and evaluate some of the *theoretical hypotheses* (following Giere) underlying our idea of how to plan didactical sequences or units for science teaching. Classrooms where advanced student teachers and recent graduates of our Instituto CeFIEC (a regionally recognized center for science teacher education) are teaching serve as empirical field for the validation of our theoretical formulations.

During the planning of all these interventions, we have implemented a series of extremely varied strategies, but which share a number of foundational theoretical elements that serve as didactical guidelines. Didactical guidelines are key ideas for praxis taken from the theoretical corpus of didactics of science; they can shape the task of designing classroom teaching (the Spanish researchers Marchán-Carvajal and

Sanmartí (2015) propose a similar idea, which they call "*criteria* for the design of didactical units").

Didactical guidelines are construed as very specific classroom "recommendations" entailed by established theoretical knowledge in our community of science education. In the following sections, I will discuss three of such guidelines, which I have defined on the basis of accumulated research and innovation in my group. Those guidelines are called: levels of representation; metacognitive regulation of analogies; and learning models and learning about models. In a final section, I will show how these three work in didactical sequences on the topic of atoms designed for primary, secondary and science teacher education.

3.3.1 Levels of Representation

I adhere here to a working hypothesis that we as a group have developed in a number of publications (e.g., Galagovsky & Adúriz-Bravo, 2001, 2004): that one of the main differences between experts and novices in science lies in the *richness* and *mobility* of their representations about natural reality. Experts are able to manage concrete and abstract representations of reality that are of *symbolic* nature, that is, they are not a "reflection" or copy of reality, but a re-elaboration *mediated by theoretical categories* and *supported on inferential relations*.

Within the rich and dense family of representations that experts in a scientific field possess and employ, the theoretical models of reference (scientists' models) and its multiple transpositions, which in this chapter I have called didactical models, are included. Experts are competent in the use of a high number of markedly varied analogical models, analogies, metaphors, and concrete representations, among other types of *second-order representations* on scientific models. All this collection of representational tools appears, in experts, self-regulated by a highly developed *monitoring* metacognitive system. These second-order operations allow expert scientists (and science teachers) to have explicit knowledge of the scope and limits of their models on systems (scientific models) and of their models on models (didactical and analogical models).

Expert knowledge is made explicit when *expressed* in some specific language (natural language, specialized jargon, mathematical equations, computer simulations. . .) (Gilbert & Boulter, 2000). Experts have great representational "mobility" when expressing and using models, which is demonstrated in their *coordinated* use of different expressive resources. Students receive teachers' discourse through its syntactic aspects and the vocabulary used; on the basis of this, they are supposed to construct knowledge, assigning content to what they hear or read: here is where *semantics* is introduced (Galagovsky & Adúriz-Bravo, 2004). In their way towards learning how to competently use the representations that constitute didactical models, students have to adapt or adjust their own initial mental representations -which are undoubtedly very different from those of science experts. They can be helped in this process by the mediation provided by the analogical models presented by their teachers.

The first didactical guideline derived from these results of research is that, in science classrooms, sustained explicit and aware work on the various "converging" scientific representations of a phenomenon can scaffold students' appropriation of the didactical model that accounts for that phenomenon. My proposal here is that it is important to transform some carefully selected natural phenomena under study into "school scientific facts", expressed in robust sign systems, so that these can *function* as initial versions of the didactical models prescribed in the curriculum (Izquierdo-Aymerich & Adúriz-Bravo, 2003; Adúriz-Bravo et al., 2005; Adúriz-Bravo, 2022). These models-in-progress (or "precursors") should be explored in different, complementary modes of representation (Adúriz-Bravo, 2022).

3.3.2 Metacognitive Regulation of Analogies

There is abundant literature in didactics of science encouraging the use of analogical reasoning in science teaching in the different educational levels (e.g., Clement, 1993; Gilbert, 1993; Dagher, 1994; Glynn, 1995; Aubusson et al., 2006, among many others). However, and considering the numerous difficulties that researchers have recognized in the implementation of analogies for teaching, a number of schemas or "templates" to structure instructional activities based on analogies and control their implementations have been advanced. Such schemas aim at working with analogical models in the classrooms so that the maximum profit is obtained and the most usual risks of confusion or misinterpretation are avoided. One of such schemas, as I have mentioned earlier in this chapter, is the analogical model for science teaching (AMST) (Galagovsky & Adúriz-Bravo, 2001; Adúriz-Bravo & Galagovsky, 2003).

Accordingly, the second didactical guideline here suggests to sequence the cognitive-linguistic operations in AMST (or in any implementation of analogies in science teaching) on the basis of two ideas recognized in didactical research. In the first place, that a fruitful way of working with scientific analogies should be to "emulate" the procedures that scientists deploy in their practice, including identification of problems, generation of hypotheses, inference of models, selection of evidences, and construction of the best explanations (Adúriz-Bravo, 2020). Secondly, that a continuous "back-and-forth" reflection between analogical and didactical models, of strict metacognitive nature, is indispensable so that both kinds of models are re-signified and stabilized by mutual enrichment.

In order to implement this guideline, AMST is developed in four stages (called "moments": Galagovsky & Greco, 2009): 1. a first, *anecdotal* moment where the analogy is presented as a self-contained problem, with little connection to the scientific topic, and instructions are provided to students to solve it; 2. then a moment of *conceptualization* of the analogy, where consensus is sought among participants on some fundamental concepts that were used in solving the analogical problem; 3. a subsequent moment of *correlation*, where the scientific content to be learned takes meaning by comparison and contrast with the meanings discussed when dealing with the analogical information; and 4. a moment of metacognitive *reflection*, where students become aware of the conceptual bridges (Glynn, 1995) they have built between source and target, the wrong or unproductive similarities they have discarded, and the new substantive relations that they have learned. It is in this last moment where scope and limitations of the analogical model are discussed in plenary and, consequently, *the very nature of models as sophisticated theoretical representations can be examined*, as it will be pointed out in the next subsection.

Beyond the use of this particular sequence of AMST, the second guideline for planning didactical units recommended here suggests *generating explicit spaces* in our teaching for a sort of "metacognitive vigilance" over analogies. Teachers need to encourage their students to make structural and functional *transfers* between source (analogical model) and target (didactical model) that disregard anecdotal or superficial features and concentrate on those similarities for which the analogy has been *historically* proposed in science or in education. At the same time, teachers should explicitly ask students to think on the potential of these analogies they have been using as "points of entry" to didactical models and, in direct connection with the next guideline, on the nature and role of both kinds of models as scientific representations.

3.3.3 Learning Models and Learning about Models and Modeling

Another central element of this approach to planning didactical units is the attention I pay to the *epistemological dimension* in scientific education, which has been called the "nature of science" (Matthews, 1994; McComas, 1998; Adúriz-Bravo, 2005). I believe it is important for students to reflect, through "metamodels" (that is, epistemological models), on what science is, how it has changed throughout history, and how it relates to society and culture (Adúriz-Bravo, 2005).

In this sense, I suggest as the third didactical guideline that it is important to work *explicitly* on the cognitive, linguistic, material, and social processes that occur in science classes when meaningfully learning science content, and then explore the similarities and differences of those processes with scientists' activity (Lozano et al., 2013). This would be a solid path towards building a genuine school scientific activity in which models and arguments are accorded a central role for the advancement of scientific knowledge in the "context of production".

On the other hand, I believe that, in planning any didactical unit for science teaching, there should be prominent space given for discussion on the role that the *epistemic* activity of modelling has played throughout the history of science. During classroom work around some important models of science, teachers should create an appropriate *context* to foster epistemological discussion on the very construct of model, a laboriously conquered idea in the history of science.

The suggestion is then to insert a variety of carefully designed nature-of-science activities *on the specific topic of models* (such as those presented in Adúriz-Bravo, 2015a, 2015b, 2017, 2018, 2021a) in the didactical sequences on the different science topics that are deployed in teaching.

3.4 How Guidelines Work in Didactical Units: The Case of Teaching Atomic Models

One of the key topics in natural science on which I have been working in more depth from this perspective of models and analogies is that of the *structure of matter* (see, for instance, Couló & Adúriz-Bravo, 2010; Adúriz-Bravo, 2015b). The science curriculum for "basic" and "upper" secondary levels (in Argentina, with students between 12 and 18 years old) prescribes for this topic a standard *history-based* approach, often very linearly executed, which transposes some of the various atomic models postulated by science from ancient Greece up to World War II.

The idea of "following" the theoretical changes in this field of science seems very suitable for working *on the epistemological dimension* of this piece of school scientific content, and for this reason, I maintain it in many of the didactical interventions designed with my group. I find that it may be convenient to reduce the diversity of historical atomic models to the classic series: Democritus-Dalton-Thomson-Rutherford-Bohr (see Oliva et al., 2015). In order to achieve coherence with the cognitive model of school science, each atomic model should be understood and taught, within this proposed sequential presentation, *as a theoretical "achievement" for the solution of a concrete problem.*

To this general conception of didactical units for the structure of matter, I add the three ingredients that I presented in the previous section as didactical guidelines:

1. coordinated use of a large number of diverse representations (scientific, didactical, and analogical) on matter and atoms, promoting critical (metacognitive) reflection on those;
2. epistemological vigilance on the introduction of elaborated analogical models (with or without the AMST sequence presented above) in order to explore the *conceptual transitions* between the different atomic models in terms of the introduction of new ideas to face anomalies and difficulties; and
3. within the epistemological dimension of the nature of science, well-founded references to the provisional nature of models and their analogical character with respect to real systems (Adúriz-Bravo, 2012, 2013).

Some of the didactical units on the atomic structure of matter that I want to discuss in this section as an example of the implementation of the theoretical developments of my group *were elaborated by prospective and in-service science teachers* in collaboration with myself and other researchers. From those units, I will select and comment some didactical activities, already implemented and evaluated in various settings in six countries of Ibero-America, that I believe are the direct result of the *operationalization* of the didactical guidelines contained in the previous section.

Many of our units start with "classical" didactical activities designed to discuss the nature of science, *and specifically of scientific modeling*, with students. The main objective of those activities is to understand *what models are and why we need them* (Grandy, 2003). In this kind of activities, a traditional "black box" game can be used, so that the emphasis of the class is put on formulating hypotheses as a cognitive-linguistic competence.

After performing a canonical black-box activity, we suggest the presentation of a (brief) text on the nature of science. With the aid of it, the science teacher can seek consensus in the class towards understanding the model of the (content of the) box *as a set of theoretical hypotheses* that have been proposed to explain the "enigma" of its odd behavior. In this type of activity (performance + conceptualization), it is explained that scientific hypotheses arise *by making (abductive) inferences* on the non-visible content of the box on the basis of simple physical models on the mechanic, acoustic, elastic, electric, etc. behavior of materials.

A second set of activities that we have tested explore the structure of matter in a dialogue between two levels of organization and representation: microscopic and submicroscopic. For instance, students are asked to imagine an (inexistent) "ultra-magnifying glass" capable of seeing the intimate structure of matter and to draw and write the result of various observations that would be made with such a device. During this kind of activity, concrete representations (photos, drawings, schemas, X-ray images, electron microscope images, etc.) are presented and correlated. Later, students with the aid of the teacher elaborate concrete representations (*scale models*) of the explanation that Democritus, through the use of his extremely parsimonious particulate model of matter, would give to the states of aggregation.

Some other of our didactical activities are devoted to introducing the historical sequence of atomic models (from Democritus to a more or less current model, highly symbolic and mathematical) *in terms of problem solving* and not just as successive discoveries of geniuses (see Niaz & Rodríguez, 2000). Through excerpts from different science textbooks of diverse level of difficulty, the historical scenes are described and the concrete phenomenon to be modeled is identified.

In a particular subset of activities that we have designed, the emphasis is put on making sense of Rutherford's proposal of an atom with a nucleus in an attempt at understanding the limitations of Thomson's model *to account for the electrical behavior of matter under particular conditions*. With every introduction of a "new" atomic model, students are reminded that we are not modeling the atom per se, but rather some aspects of its nature and functioning.

Many of our didactical activities hinge on the construction of "concrete analogs" of the different historical "atoms" (i.e., the structural-functional units of matter postulated at different times, rather independent of the current, extremely specialized meaning of atom). Concrete analogs (Galagovsky & Adúriz-Bravo, 2001; Adúriz-Bravo, 2005) are elaborate scale models that transcend the mere pictorial representation of the object in three dimensions, but are rather functional substitutes working on the basis of theoretical principles. When using their atomic models, students are always asked to make explicit the divergences between them, the (abstract) theoretical model behind, and the phenomenon that is being modeled.

Activities for synthesis, evaluation and transference usually ask for textual production (Adúriz-Bravo & Revel Chion, 2014). For instance, students are demanded to write a paragraph where they explain their position on how matter is constituted within the context provided by a particular research question (solution, electrification, spectra, radioactivity…). Additional requirements are introduced: these texts should be understandable by non-experts (their classmates, for example), and they should contain arguments in favor of the model that they are using. To satisfactorily answer this task, critical assessment of the different atomic models is necessary. Along the execution of this kind of activities, a metacognitive overview on the foreseeable divergences between the atomic models prescribed as content to be learnt (didactical models) and the "mental models" that students maintain is encouraged.

3.5 Final Thoughts

In the collaborative planning of the didactical units briefly reviewed in the previous section, the three didactical guidelines described in this chapter are introduced through "scaffolding" teachers' designs. The process achieves teaching products with a strong basis on theoretical principles of current didactics of science. The solidity of the theoretical foundations is revealed in the activities in the fact that many of the instructions that should be proposed by the teachers to their students entail the production of school scientific argumentations.

Another key point that shows that our designs are supported by valid theoretical frameworks in didactics is the fact that they coincide in many aspects with proposals published by Niaz and Rodríguez (2000), Marchán-Carvajal and Sanmartí (2015) and Oliva et al. (2015) for teaching this same topic.

The analogies in the didactical activities, applied in accordance with the recommendations of the AMST proposal, turn into "anchoring knowledge" (Glynn, 1995) in the cognitive structures of students. The constructed analogical knowledge serves as mediator (or "bridge") insofar it contains concepts that will facilitate the processing of the scientific information that will be introduced with the didactical models on the structure of matter (Clement, 1993).

The articulated kind of work that our units and activities propose between didactical and analogical models implies conceptualizing both tools as complex kinds of representations. Accordingly, these kinds of representations should be carefully "monitored" with metacognitive processes, and students should reflect, *from a metatheoretical level*, on the function they play in the scientific enterprise.

In this brief final section, I also want to highlight that the construction of this chapter has entailed a systematization of a number of ideas that my research group has constructed in the long period of two decades. Along the way of theoretical development, I have been able to determine that I am also using analogies in various, more or less formalized didactical strategies directed to teaching modeling and argumentation.

Finally, a strongly critical reflection on the research processes that I have presented is that, in my group, we are still lacking more instances of rigorous evaluative research to assess the impact of these "guideline-based" didactical innovations on the teaching and learning of school scientific models and on the professionalization of science teachers.

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Chapter 4
Experimental Practices in the Process of Scientific Enculturation

Anna Maria Pessoa de Carvalho

4.1 Introduction

Over the course of the last 50 years, research in didactics of science has produced knowledge and provided us with the support to have a minimum of certainty when planning courses aimed at encouraging students to produce significant knowledge, not only about the content of scientific disciplines but also, and primarily, about the process of constructing science itself. However, if a large fraction of society working in the teaching of natural sciences accepts the theoretical references for planning teaching, empirical data on the knowledge effectively produced by students in courses, mainly regarding the acquisition of the process of constructing science, that is, scientific enculturation, are still being obtained, and numerous studies have shown that teaching – including university teaching – has transmitted empirical-inductivist views of science that are far removed from how scientific knowledge is constructed and produced (Matthews, 1991).

In interviews conducted with higher-level professionals about the physics classes they had in high school (Carvalho & Gil, 2001), we found several testimonies of the type "I didn't understand anything the physics teacher said up front... it was as if he spoke another language... no matter how hard I tried, I couldn't understand where he wanted to go with all that." Statements like these show that there is a deep abyss between the teacher's action and the students' understanding, and that teaching physics involves more than challenging prior ideas and trying to replace them with more consistent theories from a scientific point of view. It is necessary for the student to perceive that the set of theories presented by the teacher makes some sense, and

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primarily, to understand physics as a different way of thinking and talking about the world and to begin to understand that other language –the language of science– (Cappechi, 2004).

Newton et al. (1999) propose the metaphor of learning science as a process of enculturation and show the need for the student to enter a new culture, to understand and try out its practices, values, and language. The authors start from the view of science as a specific culture that has its own rules, values, and language, and focus on teaching science as an enculturation, that is, as a process of assimilation of this culture by the students. This new conception of teaching allows us to understand the difficulty students face because in physics classes they feel, and rightly so, as if they were foreigners entering "another country," whose language and customs are strange to them.

In the same vein, we find works such as those by Lederman (1992) and Candela (1997), who identify some classroom practices that favor the change in students' conception of science, such as: frequent teacher-student interactions, active student participation in problem-solving, emphasis on teacher-guided questioning within an encouraging and risk-free environment for them. Increasing student participation in class and thus making them intellectually active seems to be an important and necessary condition, but not sufficient, to discuss how experimental activities, such as investigative demonstration and open laboratory, can contribute to teaching that fosters scientific enculturation. When planning such activities, we should seek approaches characteristic of scientific culture.

As Gil et al. (2001) pointed out, it is necessary to establish what should be understood as an acceptable view of scientific work, always being aware of the difficulty in talking about a "correct image" of the construction of scientific knowledge, especially if we consider that we are dealing with the teaching of physics in basic and secondary education. However, we can look for common points in the productions of epistemology in the second half of the twentieth century, and set aside the various interpretations and points of divergence, as our goal is to extract some basic propositions about scientific activity that can be absorbed in teaching activities, to stimulate the process of scientific enculturation and that, at the same time, can be achieved in laboratory classes.

We must fundamentally remember that science is a human construction about nature, and not nature itself, and that teachers should take advantage of experimental activities to enable students to perceive the scientific constructions (explanations) about the phenomenon (its concepts and laws), developed by generations of scientists. Science has built (and continues to build) concepts, laws, and theories to explain natural phenomena, and it is these concepts, laws, and theories that the teacher must teach. Moreover, it is not only the product of science that must be transmitted to new generations, but more than the product, it is the process of constructing science, the scientific culture from its various perspectives. This human construction, this different perspective of seeing the world, with its hypotheses, its logics, and its languages, is the main focus of teaching in experimental activities.

Therefore, when planning experimental activities and the verbal interactions that should occur there, we propose:

> Observe if the activities offer students the opportunity, even if not consciously, to overcome the empirical-inductivist conceptions of science and if they are "living a science" in which hypotheses guide the search for data. We can observe this important point by seeing if, when trying to solve the questions (experimental) proposed by the teachers, they do so by formulating hypotheses based on their prior knowledge (spontaneous in basic education and already structured in secondary education), and if they subject them to tests, since as we have mentioned earlier, many studies have shown that teaching often conveys empirical-inductivist views of science that are far from the process of constructing scientific knowledge (Matthews, 1991).

Another important point for overcoming empirical-inductivist conceptions of science is to observe how argumentation develops in these classes and if hypothetical-deductive reasoning "if/then/therefore" (Lawson, 2003) is used.

Observe if the classes are providing the opportunity to incorporate the essential role of mathematics in scientific development. We can observe if teaching promotes the enculturation of this aspect of scientific knowledge if, when the teacher and students handle data, they first make a "qualitative analysis" concerning the main variables of the phenomenon and if they express this relationship through proportional reasoning, which is the basis of mathematical language in the sciences (Lawson, 1994, 2000a, b). In addition, in secondary education, when mathematical tools (graphs, equations, formulas) are used, if teachers propose questions about the use of these tools, relating them to scientific explanations and making the translation from the conceptual language of physics to mathematical language and vice versa.

Observe if experimental activities allow the transposition of learned knowledge to social life, seeking the complex relationships between science, technology, and society, trying to generalize or apply the acquired knowledge, relating it to the society in which they live. Among the experimental practices used in natural science classes taught in basic education, we will discuss and exemplify investigative demonstration and open laboratory.

4.2 Investigative Demonstration as an Experimental Practice in the Classroom

A demonstration class can simply present a natural phenomenon (physical, chemical, or biological), which is undoubtedly better than just talking about what happens in nature. But in these cases, demonstrations have the sole purpose of illustrating what has been said, verifying content already taught, or showing students that the teacher was right. This is a rather small objective for a natural science course and makes students, even good ones, not feel the need for this type of class. From our point of view, a demonstration should present not only the phenomenon itself but create the opportunity for the scientific construction of a specific concept related to that phenomenon, and this is the first major care we must take when preparing an investigative demonstration: being aware of the epistemology and knowing how to distinguish between a phenomenon and the concepts involved in it.

The phenomenon can be shown as an event of nature, while the concept is an abstraction, usually an explanation for the phenomenon and not directly visible: it must be logically constructed, first with words, and then translated into mathematical language.

The second care when planning investigative demonstrations is to seek a problematizing question that simultaneously arouses curiosity and guides students' vision towards the relevant variables of the phenomenon to be studied, so that they pose their own hypotheses and propose possible solutions. It is always necessary to keep in mind the fact that Osborne et al. (2001) draw considerable attention to: school science often presents arguments based more on authority than on justifications, ignoring aspects of scientific argumentation.

In demonstration classes, this is quite common, as for the teacher the phenomenon shown is often an authoritative event, and they forget about the scientific argumentation related to conceptual constructions. Therefore, if we want students to build scientific knowledge, we must create situations that involve intermediate questioning that leads them, little by little, to express themselves in scientific language, as Kress et al. (2001) show that learning scientific language contributes to students forming an idea of what science is. And the construction of this learning goes through situations where students have to think and justify their ideas, intentionally clarifying the reasoning displayed.

Sometimes, when the teacher manages to propose a "good" question, the predictions or anticipations that students develop, based on their spontaneous conceptual schemes or other references, oppose experimental results. These facts can create what has been called cognitive conflicts in research on teaching natural sciences, that is, when students' spontaneous ideas or their explanations about certain phenomena clash with what is observable. And overcoming these cognitive conflicts leads to effective learning, and investigative demonstrations are the best teaching activities for cognitive conflicts to appear, in the form of students' hypotheses, which are then discussed and overcome by observing the reality of the phenomenon.

4.3 Some Examples for Discussion

As a first example, we will present an investigative demonstration class in geometric optics where the teacher aims to build the concept of critical angle. When explaining refraction, the teacher can say that when light passes from a more refractive medium to a less refractive one, it undergoes total reflection from a certain angle. But with a flashlight and a semicircular glass block, it is easy to show the light passing from the glass to the air and demonstrate the phenomenon of total reflection. Whoever sees how the refracted light in the air suddenly changes direction and reflects back into the glass will not forget that phenomenon or that class. Of course, from looking at and seeing the phenomenon (the teacher must repeat the experiment several times for the students to see what happens) to understanding the concept of critical angle, there is a considerable distance.

A simple problem would be to ask students to think about what happens when light passes from air to glass and then from glass to air. Refraction would be the most feasible hypothesis – as it is an everyday concept, even already studied previously – and when they see total reflection in the light passing from glass to air, the teacher could ask about possible explanations, prompting students to argue and try to "look" at the phenomenon again to see what they had not seen. They almost never manage to "see" the weakly reflected rays: the discussion must be raised, the teacher's answers cannot be evaluative but eliciting, making students think from all points of view. The critical angle will undoubtedly appear as a logical framework separating the angle of incidence where refraction can still occur and the one where that phenomenon no longer occurs.

From that point, the concept of critical angle was reached with or by the students, and the teacher can now take up the statements they used to describe it and, first, proceed to a conceptual systematization, that is, move from the everyday language used by the students to the scientific language of the correct definition of critical angle, and second, translate the oral language used by the students into the mathematical language expressed in the critical angle formula: a necessary step, but extremely difficult for students to take on their own. Teaching physics is teaching students to express themselves in mathematical language and to understand that language, and the best way is for them to understand the mathematical meaning of each statement made. Going back and forth from the phenomenon to mathematics, and from mathematics to the phenomenon, is one of the main and most difficult objectives of teaching physics.

As a second example, we will describe an investigative demonstration recorded on video during a course on Thermology and Thermodynamics (Carvalho et al., 1999) for the middle level, in which a cognitive conflict was created because the spontaneous ideas or explanations about the phenomenon presented by the students conflicted with the observable facts. In other words, the predictions or anticipations developed by the students within spontaneous conceptual schemes or based on other references clashed with the experimental results.

The teacher had already given lessons in which the following issues were raised: the distinction between the concepts of temperature and heat, the propagation of heat, and a sequence of classes in which, using the history of science, the kinetic-molecular theory was introduced as one of the possible explanatory models for the phenomena studied. They began to see the phenomena of expansion, and the teacher proposed a fairly simple demonstration of volumetric expansion with a balloon attached to an Erlenmeyer flask, heating the assembly with a lamp. The following question was posed to the class: "What will happen to the balloon if we heat the system presented here?[1]".

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[1] The complete transcription and analysis of this class are published in Cappechi, 2004.

The group suggested that the balloon would fill up, but while there was consensus on the prediction of the phenomenon (the balloon filling up), the same did not happen with the explanation:

Student 5: "It's because hot air rises." Student 12: "Because of the hot air."
Student 5: "Because hot air is lighter and rises [opens arms in the air]."
Student 12: "Because it expands."

These are some examples of the students' phrases that show they are looking for an explanation for the phenomenon, which is emerging, but they provide isolated arguments without justifications. We can see two types of explanations "the air is hot and rises" and "the air expands", which from the students' point of view are equal or complementary. The teacher tries to draw the students' attention to the existence of different ideas, but they continue to delve into the same thing without noticing any conflict. The teacher proposes a new challenging question: "If we continue heating it, but turn the flask upside down so that the balloon is facing down, does that mean it will empty?"

Student 15: "Yes, it would empty... if the air had risen, the balloon would empty."
Teacher: "... if the air were rising, the upside-down balloon would have to empty...".
Student 15: "But the air is not rising... it is expanding... so it won't empty...".

[The teacher demonstrates.]

Students: "Ah..."

We now see that student 15's argument is fully structured, as it presents a justification and a hypothetical-deductive thought that was later confirmed through empirical experience.

Teacher: "We have seen that hot air rises, and why is it now going down? Now the one above pushes the one below, why? Why does it want to...?"
Student 2: "It expands."
Student 6: "It is expanding." Teacher: "And why does it expand?". Student 2: "Because it is heating up."
Teacher: "Why does it expand when it heats up?". Student 5: "Because it agitates."
Teacher: "It heats up more, it agitates more, it takes up more space and keeps the air down there. What is this called?"
Student 10: "That's what we want to know."
Teacher: "So, is it not the same as what we saw in the other class?". Student 8: "No."
Teacher: "What we have just seen is called volumetric expansion..." [the systematization of the new knowledge continues].

This part of the class transcript shows that the students actively and intellectually participate during the teaching, reflecting that they had indeed learned the content taught in previous classes, and that they now managed to distinguish the phenomena. Guided by the teacher's argumentation, they participated in the elaboration of the "whys" and felt the need to create a new concept (indeed, a new word) –volumetric expansion– to respond to this new causal explanation.

4.4 The Investigative Laboratory

Since always, laboratory classes, with their own space and materials for students to work in small groups, have been part of the planning of science teaching, from kindergarten to university. However, not all teachers are familiar with this activity. Most of the time, the laboratory class is approached as a separate activity in the conceptual development to be taught, and serves more to verify what the students have learned in theory (and for this reason, the classes turn out tiring and boring), instead of being a place (and time) to introduce students to creative research (and, therefore, more exciting).

In the 1960s, criticism began against the laboratory for being a "cooking recipe," in which students followed work plans previously prepared by teachers, and entered the laboratories only to read and follow what was written; group work was characterized by the division of tasks and not by the exchange of ideas. Around the concern of finding out how laboratory books and manuals are produced, there is research on laboratory manuals and also on science classes taught in secondary schools, seeking to determine the possible degree of intellectual freedom that teachers give to their students.

The lowest degree of freedom in lab guides corresponds to the so-called "cooking recipes", in which the student only has the intellectual freedom to collect the data. The problem, the hypotheses, the work plan, and even the conclusions about the data to be obtained are already proposed. Such classes, unfortunately, are much more common than we would like and can be seen to this day in our schools and in our laboratory manuals. Often, we could even rate the classes (and manuals) with a degree 0 (zero) because we do not even find the problem and the hypotheses well discussed in the texts. We find only a theoretical proposal and from this, we move directly (without discussing the working hypotheses) to the work plan that the students must execute. In such cases, the conclusions are already given, and it is only necessary to verify that the theory is correct. It seems logical to us that in these cases, students "cook" the data. In essence, in that type of laboratory class, students only learn to divide tasks and cook the data to get good grades.

A second degree of freedom is characterized by giving students the freedom to draw conclusions from their own data. This, which seems logical to us, is not often found, as it requires a structural change in the problem's approach. They cannot be problems of the "Prove that..." type, which have closed conclusions. For example, instead of "prove that the acceleration of gravity is 9.8 m/s^2", the problem would have to be "what acceleration can you obtain and why?". This small change already significantly modifies the classes, mainly concerning the attitude objectives that are intended to be achieved.

In higher degree of freedom, students are invited to develop the work plan to obtain the data that will lead to their group's conclusions or receive only the problem from the teacher and take charge of all intellectual and operational work.

In the most open type of lab guides, with students as a "young scientist", they can achieve intellectual freedom, which is still the dream of many teachers and even scientific societies, as in all countries we find government programs such as "Young Scientists", which value and award the student-researcher.

There are two changes in directives in the conception of teaching natural sciences, now at the beginning of the twenty-first century, that influenced laboratory activities. The first is that science education should be for everyone and not just for those who have an aptitude for these subjects; and second, the reformulation of the teacher's role, who changes from transmitter of established knowledge to conductor of their students, helping them build their new knowledge and seek scientific enculturation.

Thus, we propose a new gradation to study the degrees of freedom that teachers offer their students. Here, the lowest degree of freedom that we have described would not make sense any more, as we agree with Bachelard (1938) when he argues that all knowledge is an answer to a question, and as we want students to build their knowledge, we teachers have to propose challenging and interesting questions that can be solved through experimentation. Here too, with more possibilities than investigative demonstration, all aspects of scientific culture should be observed.

In our new Degree I of freedom, the teacher will propose the problem and the hypotheses, and the work plan will be made with their guidance, but always trying to create, through questioning, environments conducive to the intellectual participation of students. In the task of obtaining the data, the main role corresponds to the students, and the teacher will always be on hand, always available, to clarify any doubts that arise. The conclusions should not remain only with the students, recorded in a report submitted to the teacher: they should be discussed, under the teacher's direction, with the entire class, so that, now, the possible solutions to the proposed problem are collectively found. This is an important point of scientific enculturation, as no scientist works in isolation, and all findings must be analyzed together with the community of other scientists.

In our proposal for grades II and III, step by step, more intellectual freedom will be provided to the students. In our proposal for the highest degree of freedom students may be able to think about a problem and solve it. The role of the teacher in that case is that of a guide, as in master's and doctoral courses.

4.5 Some Examples for Discussion

As a first example, we will present an open laboratory whose proposal is one of the initial classes of a Kinematics course aimed at introducing students to the graphical and mathematical languages used in physics, and part of a previous content which is the concept of velocity that they bring. The experimental material for each group of students consists of a hollow, transparent PVC tube, approximately 1 m long and two centimeters in diameter, a ruler, a clock that marks the seconds, and a small bug (a tiny creature that can move through the tube).

The problem posed to the class is: how can the movement of the bug inside the tube be described?

Before starting to structure the hypotheses, it is interesting to let the students play a little with the bug. Then, some questions should be formulated, such as: how are we going to describe the movement of the bug? What variables show the movement? How are we going to measure it? And if the bug doesn't move, can we describe its non-movement?

At this stage, the teacher must be attentive to stimulate and direct the discussion, but without giving the answers. Students have to do the experiment, realize what goes well and what goes wrong. It is necessary to let them make mistakes, as studies in learning have shown that when students understand why their own reasoning is wrong, from there they better understand the correct reasoning. Above all, the teacher should not propose the way to systematize the data, that is, how to make the table between the space and time variables.

When students begin to collect the data, a significant fraction of the groups fix the space (for example, 2 cm), and try to see how long it takes the bug to cover that space. Now is the time for the teacher to intervene and ask: "and if the bug decides to stop halfway, what are you going to do?". It is important that they feel the impossibility of answering and the need to fix the time and measure how much the bug advances in that time interval. This is an essential learning for all natural sciences. It is important that they feel that in natural phenomena, time is always the independent variable, and precisely for this reason, the mathematical formulas that describe nature are always written as functions of time, for example: $y = f(t)$ or $v = f(t)$, etc.

After the students have collected the data (an activity that takes no more than 15 min), the teacher can ask each group to plot the graph (y x t) and propose a series of questions to promote a complete understanding of that language. How to find out through the groups' graphs which of the bugs walked faster? Where, in the graph, is the bug's speed represented? What is the graph of the bug that did not want to walk? How is the mathematical function of space written through the graph?

This is usually a very fun laboratory class that students still remember years later, and one of the best for them to build a friendly relationship between physics and other languages used in the sciences.

As a second example, we will present an open laboratory designed for a second-grade course (children aged 8–9). Here we propose a problem whose solution is the relationship between height and velocity of the same body – thus creating the conditions to later introduce the concept of energy – and also to provide the opportunity to develop hypothetical-deductive reasoning "if/then/therefore". We call this laboratory "the basket problem", and in a group of one of the schools where such laboratories are part of the planning, we have recorded a class on video and transcribed it for analysis (Carvalho, 2003). We will present here some of the dialogues to exemplify the students' reasoning.

Each group is given a small ball and a rail composed of two parts, one inclined and one straight. At the end of the straight part, we place a small basket. The apparatus must be set up in such a way that the ball, after its movement along the rail, can fall into the basket. The problem posed to the students is to find the height at which the ball should be placed on the rail so that it falls into the basket.

Each group takes an average of 10–15 min to solve the problem. Then the teacher collects the materials, disassembles the groups, arranges the students in a circle, and starts a discussion by basically asking them how they managed to achieve what was wanted and why they did it that way. The purpose of such questions is for students to become aware of what they did.

By starting with the question of how they managed to solve the problem, the teacher encourages the participation of a large number of students to tell her and their classmates what they did. As they recount their actions, the experimental evidence and the relationship between variables become increasingly complex. Students begin to systematize the hypothetical-deductive reasoning model "if... then... therefore."

Student 2: "But you can't put it too low because it goes very slowly and that doesn't work, you have to put it a little bit up and a little bit down."

Despite the difficulty in expressing himself, this student already offers an "if... then" reasoning that can be paraphrased as follows: if you put it too low, then it goes slowly; in addition, the beginning of the relationship between the variables of height and speed can also be glimpsed.

This relationship between variables is also mentioned by the following student:

Student 4: "If the little basket were further away, it would fall there [gestures], if it were closer [gestures to indicate a shorter distance from the basket], you put it in the middle."

As the class discussion progresses, students present their reasoning in an increasingly systematized way, and later on, student 7 synthesizes it as follows, using two cycles of "if... then" reasoning and taking up a third piece of evidence to reach the conclusion:

Student 7: "It's like this, if you put it up there, [then] it picks up speed. And if you put it lower, [then] it's going to lose, so I put it in the middle, halfway between up and down [third evidence], and that's how it went down and fell into the little basket."

It is important to emphasize that while students construct hypothetical-deductive reasoning, they also construct proportional reasoning, establishing relationships between variables, in this experiment represented by the height at which the ball must be placed on the rail, and its speed at the end of it to reach the little basket. However, the students' reasoning is only completed, that is, they only manage to express themselves according to the hypothetical-deductive reasoning model "if... then... therefore" from the question about physical causality (the why of the phenomenon) that the teacher asks after everyone has explained how they did it:

Teacher: “Let’s pay attention, why did we have to release the ball from that position to make it fall into the little basket, can anyone explain it to me?”

From this question, little by little, students develop their reasoning more precisely; thus, student 7 explains:

Student 7: “Because if you put it a little closer, [then] it’s going to pick up a little speed, but not much, and [therefore] it falls [into the little basket].”

Although the student does not say “then” and “therefore,” these words are understood in his presentation.

Student 2, a little later, also completes his reasoning already outlined in the first stage. Now he expresses what he is thinking and to show his reasoning he uses three cycles of this reasoning model:

Student 2: “If you put it a little higher, [then] it picks up speed and [therefore] ends up falling a little further; and if you put it very close, like, a little lower than the ‘little mountain,’ [then] it falls very slowly and [therefore], when it’s at that tip, it falls completely and doesn’t fly a little further; but if you put it a little in the middle and a little higher too, [then] it falls carefully and a little slowly and [therefore] ends up falling into the little basket.”

The most interesting aspect of this student’s reasoning is the need to refute his initial hypotheses before presenting the correct one.

We must be aware that this is difficult reasoning for all students, especially if we remember that this class was taught in a second basic education course. We find students who are still in the preoperational stage and answer the teacher’s question magically. This is observed when one of the students answers the teacher’s question about how she placed the ball in the basket by saying: “It was like a touch of magic. I put it on top of the little basket and ‘chabún,’ it fell inside.”

This happens in almost all natural science classes in the first years of primary school, but that does not mean we should stop promoting an investigative environment for students. We cannot adjust our class for those who still cannot keep up with all the stages of the formation of scientific reasoning; undoubtedly, we must respect and accept them, but we must also place them in intellectually challenging environments so that they have the possibility of developing intellectually and become aware of the relationship between their actions and what happens in nature.

4.6 Final Consideration

What we have intended to show in this chapter, either with the theoretical references presented or with the examples reported – all verified in classroom of basic and middle schools – is that investigative demonstration classes and open laboratories are privileged teaching activities to promote the scientific enculturation of new generations.

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Chapter 5
Some Culinary Preparations as a Support to Work in the Chemistry Classrooms

Núria Solsona i Pairó

5.1 Description of the Experience

A science education aimed at all audiences to form fully-fledged citizens must take into account meta-scientific content, epistemology, history of science, and sociology of science. In line with the notion of scientific competence, we want to train capable people who know, who can do, who have recognized capacity to face a situation, who possess a certain degree of mastery of skills and resources for action (Quintanilla et al., 2014a). The experience we present identifies a context in which relevant problems are posed that require school scientific activity and consequently scientific competences. That is, the culinary context facilitates the ability to transfer learning, a set of knowledge organized according to the logic of chemistry to respond to real situations and needs (Quintanilla et al., 2014b).

To achieve better learning outcomes on chemical reactions, it is advisable to consolidate the macroscopic knowledge of materials, their properties, and their changes before introducing the microscopic study, or the structure of materials, more systematically. I do not share the traditional viewpoint of many textbooks where the atomic-molecular model is a starting point, from which, through graphic models, different material systems and their transformations are described. In accordance with this approach, it is recommended to prioritize working with chemical phenomena before entering their explanation at the atomic level (Solsona & Sanmartí, 1998; Solsona, 2009).

In the introduction of the chemical change model, in the context of cooking, students experimentally study the properties of some substances such as salt, sugar, oil, and vinegar. With the aim of not limiting learning to a descriptive science, we

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work with a particle model that allows students to understand and justify the classification of substances in mixtures, solutions, and colloids. In the school's kitchen-laboratory, they prepare culinary dishes such as hot chocolate, milk with cereal, and jams, among others, and explain them at the macroscopic and microscopic level. There are at least three culinary experiments that are very useful for introducing the chemical change model: making a cake, preparing cottage cheese, and forming caramel. These are three experiments that arouse the enthusiasm of 15 and 16-year-old students, who have no problem staying a little longer in the laboratory to finish the experiments if necessary. An added reason to perform them in class, given their relevance for introducing chemical change and the possibility they offer to work on the macroscopic and microscopic justification of chemical change.

I conducted this study in a school context during the 2003–2004 academic year, the last year of compulsory secondary education, with a group of 11 boys and 12 girls aged 15 to 16, from a public school in Barcelona (Spain). The curricular proposal followed by the students is developed in the compulsory chemistry subject, which lasts half an academic year and is carried out in a culinary context (Solsona, 2002, 2003a, 2007). We have carried out various practical works, and three of them correspond to the didactical sequence of chemical change. The data from my study were obtained from the texts written by the students after the practical works and from a scientific text about what they had learned with the approximate title "Chemical Changes in the Kitchen." The text was done voluntarily.

The sequence to be followed in carrying out the three experiments deserves special mention. Throughout the 5 years in which I have developed the three experiments in class, the first 2 years in an elective subject and the following three in the common subject, I have tried different didactical sequences for their implementation. In the first years, I started with the formation of caramel and then alternated between the cake or cottage cheese, as I was not convinced of the best sequence. Today I can say that if I start with the preparation of caramel, which in culinary terms is called "burning sugar," it does not present problems if limited to caramel. But usually, students are curious to study the process that occurs if the caramel is heated further, that is, the formation of carbon. In this case, the process that takes place when sugar is heated and caramel and then carbon is formed involves at least two chemical changes. From sucrose, various types of volatile and liquid polysaccharides are formed. Finally, once the volatile polysaccharides have evaporated, carbon is formed. During the process, students think that the polysaccharides resemble the cinematic version of Tolkien's Lord of the Rings Orcs.

In the case that the didactical sequence begins with "burning sugar," students internalize that the presence of different chemical changes is necessary in any complicated process, such as, for example, making a cake. On the other hand, if we start the didactical sequence with the preparation of the cake, in which we study the chemical change that takes place from the two ingredients of baking powder: $HX + NaHCO_3 \rightarrow CO_2 + H_2O + NaX$, then there is no difficulty in interpreting the cottage cheese and the formation of caramel. Baking powders generally contain three materials: a source of CO_2, one or more acids, and a diluent. The source of CO_2 is sodium bicarbonate. The acids are monohydrated monocalcium phosphate ((H_2PO_4) $2H_2O$) and potassium tartrate ($KHC_4H_4O_6$). Milk, sour milk, fermented buttermilk, and ionic proteins of flour are acidic compounds and therefore act as acids that produce CO_2.

In conclusion, it is advisable to first prepare the cake, then the ricotta, and finally heat the sugar. The preparation of a cake is the experiment that best stimulates the complicity of the students, awakens their interest, and becomes a challenge, first and foremost, culinary, to make the cake “rise” well. And then it can become a scientific challenge, to explain what has happened for the cake to “rise,” that is, to explain the chemical change that has occurred. Moreover, it is the most creative experiment carried out by the groups, in their planning they have the maximum autonomy since the group decides the recipe or procedure to follow, distributes the initial ingredients or substances, and organizes everything to ensure success and that the culinary process is a success. It is one of the few occasions when the group works in class following their own initiative. In addition, success is guaranteed since the percentage of failures, that is, cakes that do not “rise,” never exceeds 5% per promotion.

The preparation of the cake is a paradigmatic example for learning the model of chemical change, as it is essential to work with specific proportions of the ingredients to obtain a cake that “rises” correctly and is edible. In most of the procedures used by the groups, following the recipes of their mother, aunt, or grandmother, they measure the amount of ingredients by the number of yogurts. For example, one student writes her recipe: “First, beat the eggs, add the sugar, oil, and lemon yogurt, flour, and baking powder, always making the proportions of the ingredients with the help of the lemon yogurt container.” In the following year, in High school, when introducing the concept of mole, as a measure of the amount of substance, I recall that we can indicate the amount of ingredients in two ways: with grams or with tablespoons or with the number of yogurts, as they did in the cake-making process.

To advance in the development of the chemical change model, students must also construct the model of the actions and the model of the instrument involved in the experiment (Izquierdo & Solsona, 1998). The necessary actions that students must control in the preparation of the cake and that constitute the action model are: mixing the initial substances, obtaining an emulsion, a mixture, or a solution, depending on the recipe; introducing it into the oven and heating the “mass” of the cake at a certain temperature, leaving it for a time until the cooking is complete. Sometimes, there are supplementary actions depending on the recipe, such as beating the egg whites until stiff peaks form beforehand, heating the chocolate to melt it, or reducing the size of the nuts, almonds, or walnuts, with a chopper, if the recipe calls for it. In the preparation of the cake, the instrument model consists of understanding the function of the oven.

The production of cottage cheese or ricotta is one of the experiments that students can easily perform, without the need for a large amount of equipment. With a stove or burner, a container to heat the milk and lemon until it coagulates, and a funnel and filter paper to separate the ricotta from the whey, small amounts of ricotta can be obtained (Solsona, 2003a). It is advisable to cool all the ricotta obtained by the different groups in the refrigerator, wrapped in a cloth, to be able to taste it the next day. In the ricotta experiment, the instrument model includes the thermometer and filtration. The function of the filter paper does not present problems, but the use of the thermometer raises some doubts. Perhaps at older ages, this problem does not arise, but at 15 years old, there are boys and girls who do not know how to use the laboratory thermometer and confuse it with the clinical thermometer, which is usually a clear indicator of conceptualization difficulties.

Since it is important for students to learn to ask questions about the phenomena they study, the culinary context makes this task easier compared to the usual chemical phenomena in a school laboratory. Thus, for example, after the preparation of ricotta, the working groups propose very varied questions. Some groups focus more on the most striking aspects of the process and propose phenomenological-type questions, such as: “Why does the ricotta take on this texture?”, “Does temperature coagulate milk?”, “Why do milk clots jump?” and “Why does cottage cheese explode?”. A second type of question focuses on the substances present in the phenomenon and asks: “Why do we add lemon to milk?”, “Does milk coagulate without lemon?” and “Why do some types of milk take longer to coagulate than others?”. Other groups follow the standard scheme of formulating scientific questions that they have learned in the preparation of the cake and ask: “How is cottage cheese formed? Why?”, “Why does milk coagulate?”, “Why is cottage cheese formed?” and “Why does the mass not vary in the formation of cottage cheese?”

In the culinary preparations I am discussing, I have not observed any special difficulties in the construction of the instruments. Most are well-known kitchen instruments for the students. For example, jars, forks, spoons, knives, oven molds, stove, oven, mixer, and wooden spatulas do not present any difficulty. The laboratory instruments such as the porcelain capsule, the laboratory assembly with the foot, the clamp, the ring, and the asbestos grid, present a single difficulty which is calling the porcelain capsule a bowl, in the same way as they usually call the spatula a spoon.

The experience of previous courses has taught me that a quick, easy, and approximate way to know if the students are in the process of appropriating an experiment lies in the title they write in the scientific report of it. Students are used to being creative in language classes, but they are almost never asked to be so in science classes, where scientific orthodoxy prevails. That is why I find it interesting to stimulate the imagination when writing the title of a scientific text, as well as asking for their opinion on the experiments carried out in class. The title of a student’s report is: “A very sweet coal” and says: “I have put this title because the coal is made from sugar, not because it is sweet since it is ‘inedible’“.

One group decides to perform the two experiments simultaneously, but the majority carry out the complete process, from sugar to caramel and from caramel to coal. In this case, the conclusions become a bit more complicated because two chemical changes are involved. A student writes: “Macroscopic conclusion: A series of chained chemical changes have occurred and when heating the sugar, caramel is first formed and then coal. There is an exchange of energy and gases are released. Microscopic: The bonds between the sugar atoms have been broken and several atomic rearrangements have occurred that have transformed it into caramel, and then coal. Many gases have been released and that is why the mass of the coal was less than the initial mass of the sugar". The writing of the conclusions is confusing, we cannot assure that this student, despite being the third experiment she has carried out on chemical changes, has properly constructed the chemical change as a "change of substances". However, in the experimental observations made during the experiment, she had written, at minute 8: "There is caramel of different colors and on the sides there is still a little sugar left to melt". And at minute 9: "Everything is already caramel and has small bubbles". The way of writing the observations and conclusions indicates a certain continuity in the substances, from sugar to caramel, as if there was preformation of caramel in the sugar.

With the aim of consolidating the chemical change model, in a class that was more advanced than the rest of the groups at the same level, I propose a complementary activity that consists of answering the following question: In the preparation of the cake dough, is a mixture or a chemical change made? At this point in the learning process, students are constructing the theoretical entities "mixture" and "chemical change". To carry out the debate, I divide the class in half. One half of the class has to defend that in the preparation of the cake dough they make a mixture and the other half has to justify that the preparation of the cake dough is a chemical change. At first, they refuse to carry out the activity because they say that everyone knows it is a mixture, but finally, I convince them that it is about working on the scientific justification of the chemical change they have just learned and they accept to carry out the exercise. For this, the presence of a student is essential, who is part of the group that has it more difficult: to simulate that they believe they are supporters of the chemical change and respond to the arguments of the group that argues that the preparation of the cake dough is a mixture. The ideas used to justify that it is a mixture are as follows:

"When making the cake dough, they are mixed substances. A new substance has not been formed".
"The dough has not changed".
"There has been no release of gas".
"Microscopically, the molecules of some substances are placed between the particles of other substances."

In response to the justification presented by the group in favor of it being a mixture, the ideas of the group that must simulate being in favor of the chemical change are as follows. To idea 1 they respond: "The mixed substances cannot be differentiated or separated." To idea 2 they reply: "Agreed, the mass does not change, but the external appearance and properties do." To idea 3 they counter: "Not all chemical changes are accompanied by the release of gas." And to idea 4, they respond: "Microscopically, the molecules are arranged differently than they were in the reactants. In addition, there has been a manifestation of kinetic energy."

It is not easy to verify the conservation of mass during the three chemical changes in the simple culinary experiments that I mentioned we do in class. When the class has difficulty understanding the principle of conservation of mass, it is very convenient to perform the reaction between commercial "sodium bicarbonate" ($NaHCO_3$)

and vinegar (a solution of $CH3COOH$) and collect the $CO2$ that forms in a balloon. It is a simple experiment that is very entertaining for 15 or 16-year-old students and is presented as a small investigation, in which part of the family ends up collaborating. I suggest to the girls and boys that they design an experiment at home to study the chemical change that occurs and verify the conservation of mass when mixing commercial "sodium bicarbonate" and vinegar. These are substances that are easy to obtain in most households, and almost everyone can think of using a small balloon to collect the gas released at the mouth of the bottle or container where the reactants are mixed. The difficult and fun part at the same time consists of finding out the appropriate amounts of reactants so that the balloon does not detach from the container and they do not lose part of the product of the chemical change. In this phase of the experiment design, the older sister, father, or some family member helps to test the appropriate amounts of reactants. But then, even when they do it in class, they purposely put more than necessary to be able to repeat the experiment as many times as they want.

Finally, we cannot limit the classes to the performance of experiments and the discussion of results, since there is a general consensus that they do not guarantee by themselves the learning of the model of chemical change, even if practical work is done in a context closer to the environment of girls and boys, as in the case of the kitchen. To this end, the teaching staff proposes to accompany practical work with the implementation of an instrument of a linguistic activity such as the elaboration of a scientific justification text, to give cohesion to the students' ideas.

The instructions are very precise in the elaboration of a scientific justification text of an experiment. The text must have a title, an introduction, the development, and the conclusions. The introduction must begin with a temporal connector and must specify the objective of the experiment. The development of the experiment must be concise but sufficient for another person to perform it by reading the text. And the conclusions must include the macroscopic level, the microscopic level, and the opinion of the person who wrote it.

At the end of the didactical sequence, that is, as one of the learning objectives, the students should be able to answer questions such as those included below, which can be part of the summative assessment:

1. In the cottage cheese experiment, Ivan says that from 50 g of milk and 0.4 g of lemon, he obtained 11.1 g of cottage cheese and 43.1 g of whey. Explain to him what happened and the reason why the sum of the masses of the reactants is not equal to that of the products of the chemical change.
2. Maria says that if carbon (C) is solid and hydrogen (H) is a gas, she does not understand how butane $CH_3\ CH_2\ CH_3$ used for cooking can be a gas. Explain it to her in the most convincing way possible.
3. Malika wrote a report on the cottage cheese experiment where she wrote: "The mass of the reactants is equal to the mass of the products minus 2.62 g" and gave no further explanation. Help her write the conclusion of the report where she fully justifies the conservation of mass in a chemical change.

4. In the cottage cheese experiment, Byanca did not understand well if it was a chemical change. She says that “she saw how the milk curdled while it was heated and then the milk separated from the lemon into denser clots.” What could you tell her to convince her?
5. Dani says that, in the sugar experiment, it carbonizes because its atoms release the water they contain. Explain if you agree with his explanation. And if you do not agree, indicate how you justify this chemical change.
6. Ana explains the reaction “between commercial baking soda and vinegar, saying that a new substance is formed that releases gases.” Indicate whether you agree with her explanation and if not, how do you justify this chemical change.
7. In justifying the chemical change between commercial baking soda and vinegar, Yani says that “At the microscopic level, with heat, the molecules of the reactants have rearranged, forming the products.” Try to improve her explanation.

At the end of the learning sequence of the chemical change, I propose to the students to write a text about “Chemical changes in the kitchen.” The initial thesis to justify is implicit in the title of the text, that is, it consists of asserting that in the three culinary preparations carried out in the kitchen-laboratory, there are a series of physical and chemical changes, in which substances participate, with identifiable properties and energy transfer. Throughout the justification, there are always two propositions related to each other, so that one of them makes the other appear plausible to any interlocutor. The activity was done before the end of the school year corresponding to chemistry, that is, the students had not yet carried out the microscopic simulation work of the chemical change process. That is, working with molecular models or with sticks and clay, an analogy to understand the breaking of bonds, atomic rearrangement, and the formation of new bonds between the atoms of the products. This aspect will have to be taken into account in the analysis of the justifications.

5.2 The Model of Chemical Change

Currently, one of the main orientations in research in didactics of science comes from cognitive sciences. A central idea in them is that people make internal or mental representations of our environment through internal processing or interpretation. That is, the mind is not a mirror of nature. Since science is made up of a set of facts that it seeks to explain according to one or more theories, from cognitive sciences, it is proposed that scientific knowledge is constructed by establishing a relationship of similarity between a fact and the theoretical model that interprets it, so that they come to contain each other and form a theory (Giere, 1988). The models that students build during school learning as a result of teacher intervention are largely implicit. These models allow them to explain phenomena and reason from experiments and can evolve throughout schooling.

The chemical change model is central in chemistry, as a discipline, in biology, geology, and other scientific branches. Some didactical proposals suggest that the differentiation between physical and chemical changes has no instructional utility (Borsese & Esteban, 1998), but in my opinion, it is still valid to structure the teaching intervention for learning the theoretical model of chemical change, that is, the necessary concepts for the interpretation of chemical phenomena and the relationships between concepts and phenomena, formulas, and images used to represent it. The "chemical change" model interprets chemical phenomena that are irreducible to physical phenomena, understood as a change of substances with an associated energy transfer and in which mass is conserved.

In chemistry, there is a central problem in learning that arises with the introduction of a new model, such as the chemical change model, since it is difficult to grasp the similarity between a phenomenon and other phenomena previously interpreted. The chemical change model will be simple at the beginning of learning and will become more complex as students learn more facts to explain. The goal is to overcome explanations suitable only for a small number of phenomena at secondary education. The construction of the theoretical model of chemical change must be suggested by the experimental situations presented to students in class and must allow reasoning from them. Therefore, in a learning situation, we identify the process of constructing the chemical change model used by students through the set of explanations they can develop about one or more chemical phenomena. Students have a series of disciplinary concepts grouped around specific theoretical models or theories, to form an opinion on the practical problems of everyday life and to understand the physical and technological world around them.

One of the basic objectives of the natural science curriculum is to promote students' interest in connecting science with technological applications and everyday life phenomena. The connection between laboratory chemistry and everyday life chemistry, one of the desirable objectives of the initiation to chemistry teaching, remains problematic. The claim that students should be able to recognize some of the most common chemical substances and interpret some of the most important chemical changes for everyday life has not become a reality. In addition, students should be able to explain in writing the relationship they establish between the phenomena they observe and the chemical concepts they use to interpret them.

A didactical perspective considers the relationships between science and other forms of everyday knowledge important, and for this, the research line that tries to explore the characteristics and application areas of those knowledge's, different from scientific knowledge, present in the social environment is relevant. People have different functioning registers that we activate depending on the task we want to perform. Any person implicitly constructs explanations of the phenomena that occur around them that are very persistent, general, and in many cases coherent. Everyday knowledge is one of the common ways in which we represent our practices, in which we articulate a set of ideas and concepts that allow us to act in daily life. One of the forms of everyday knowledge is women's knowledge, and this should be incorporated into the school curriculum (Solsona, 2015b).

With the aim of deepening learning processes, didactics proposes adopting a perspective in which the relationships between scientific knowledge and other representations of the world are not of superiority. If, instead of considering scientific knowledge as the most valid representation from the learning point of view, a relative status is granted to it concerning other types of knowledge, the relationships between everyday representations and scientific representations gain importance. From didactics of science, difficulties have been detected in terms of learning outcomes, and this raises the need to analyze different aspects in depth. Among them, it is worth reconsidering the didactical transposition that takes place in classrooms and the learning contexts in which it is proposed to work in class. In addition, on several occasions, we have pointed out the difficulty of selecting paradigmatic phenomena or facts to introduce the basic concepts of chemistry.

In general, people do not learn alone, but rather we do so integrating into a social context that gives meaning to what we learn. The social context of a person in a learning situation is formed by their social environment, the educational center, and the values present in them. This context is what can make one feel the need for what is missing to learn and what needs to be adjusted in the learning process. Knowledge structures originate and apply in specific experience contexts. The context in which any human activity is rooted is not configured by a series of stimuli that affect people, but rather by a network of relationships that give meaning to action. Human knowledge is contextualized knowledge.

In previous research (Solsona, 1995; Solsona & Izquierdo, 1997), we detected that students are not always able to use theoretical knowledge to interpret the chemical phenomena proposed in the school context. That is, they hardly connect the relationships established between theoretical and factual knowledge. Students have access to a smaller number of facts or phenomena than those that scientific theories try to explain. In the introduction of the theoretical model of chemical change, it is important to select a learning context that allows students to become familiar with a specific number of phenomena with certain characteristics. In the first place, involving substances that are familiar to them or that they have studied in class; including the handling of instruments that are familiar to them or that do not present great difficulty; and that their handling does not involve performing unknown actions. A learning context that meets the mentioned conditions to introduce the theoretical model of chemical change is the culinary one. My experience in an everyday context like kitchen chemistry tries to turn some culinary facts into scientific facts. The theoretical model of “chemical change” is useful for understanding the chemical changes that occur in the kitchen.

For several years, I have used the culinary learning context for chemistry because I also position myself in the line of research that seeks to explore the characteristics and application areas of those different types of knowledge from scientific knowledge, present in the social environment. School science, that is, the result of didactical transposition, must take into account the existing relationship between everyday knowledge and scientific knowledge that is the object of learning in classrooms. Furthermore, as pointed out in other works, I start from the idea that in learning activities, the relationship between the cognitive and affective aspects is inseparable from the motor field (Solsona, 1998). These three fields are activated in the learning of chemistry in a culinary context, and this allows giving importance to affective education, in a broad sense.

To construct the chemical change model, students must be able to reason from experiments. For this, it is important to have a certain mastery of the cognitive-linguistic skill of "justifying," which consists of producing reasons or arguments and establishing relationships that lead to modifying the epistemic value, in relation to the corpus of knowledge in which the contents of the justification are included.

The learning of the cognitive-linguistic skill of justifying, in our study, is approached within the framework of cooperative learning. Cooperative learning is a classroom management strategy that favors the organization of students into heterogeneous groups according to gender and the learning pace of its components. Group work is based on the practice of mutual help among students for carrying out learning activities. This facilitates learning to value individual differences and promotes the development of individual responsibility, as the classroom is organized in a multi-structured way (Solsona, 1999). In cooperative group work, with an adequate distribution of responsibilities, students train their social skills, that is, they learn to self-organize and coordinate tasks with their group peers. To achieve the formation of autonomous boys and girls who build their personal learning system, we must take into account more than just school content and the promotion of certain intellectual skills included in analytical intelligence. We cannot forget that intelligence is connected with affections and feelings, and we cannot disregard the structuring of these through activities such as promoting cooperative work compared to the little space available in the lecture class (Solsona & Sanmartí, 2011).

The questions of my study are based on previous research. In an initial investigation (Solsona, 1995), we saw that only 8% of 18-year-old students were able to develop an interactive model of chemical change (Solsona & Izquierdo, 1997). We have continued analyzing the construction of the chemical change model in students, depending on different didactical sequences (Solsona et al., 2001, 2003). Today we have reformulated the research questions in the following terms: How do students justify the chemical changes that occur in the culinary context? What relationship do students establish between macroscopic justification and microscopic justification?

5.3 Women's Scientific Knowledge

If we take into account the gender perspective, we must include in our analysis a decolonial and depatriarchal perspective (Curiel, 2015). Specifically, we propose to analyze the differences between girls and boys in scientific learning (Watanabe & Ischinger, 2009; Marbà Tallada & Solsona Pairó, 2012; Solsona, 2012b). The knowledge associated with the culinary context is considered specific to women since they have traditionally been the ones who have built, used, and accumulated culinary knowledge and have transmitted it from generation to generation (Solsona, 2010b). Women's scientific knowledge is personal, in that it may not be the same for two different women; it is implicit and sometimes "unconscious"; and it is subjective, that is, it takes into account people's point of view. Women's scientific knowledge refers to the mesocosm and is articulated with non-logical relationships;

they use multicausal reasoning or complex causality and constitute a network of relationships that give meaning to action, direct women's behavior, and gradually evolve so that there is no ambiguity between their behavior and the context in which they are applied. In this knowledge, values are central, linked, and dependent on the physical context and culture, and are governed by utility and decision-making, aimed at the effectiveness of actions and its function is to solve problems to achieve the well-being of people. The knowledge of women, whose objective is the care of people, has conceptual elements nuanced by episodic aspects, depending on the situation where they originated and their previous use. Women's scientific knowledge is expressed in colloquial language, has the intention of being particular, and tends to be presented in a narrative form.

In contrast to women's scientific knowledge, school knowledge is public, explicit, and requires awareness for its acquisition, has the pretense of objectivity, rationality, and refers to the microcosm (in chemistry: atoms, bonds, energy, electric charges) and the macrocosm (oxidation, acid rain), establishes logical relationships between concepts to build theories. School science is theoretical, focused on research, and uses multifactorial reasoning, where concepts are central despite attempts by various didactical proposals to give greater importance to work procedures and values associated with scientific knowledge. Until now, school knowledge has been presented in a decontextualized manner, has pretended to "distance" itself from reality, with an almost exclusively theoretical character and oriented towards conceptualization. School knowledge is expressed in specific scientific language, in its elaboration process it has the pretense of universality and prioritizes argumentative textuality.

Finally, it should be noted that women's scientific knowledge groups experiences, regularities, laws, and values, and prioritizes some variables and interactions that do not coincide with those prioritized by scientific knowledge. And that both school knowledge and women's knowledge have in common being the result of human activities and therefore having been constructed through social processes. These are some of the reasons why scientific knowledge should not have a higher status than other forms of everyday knowledge, such as women's scientific knowledge.

The androcentric approach to science, inherited from the past and still present today in the scientific community, underestimates women's contributions to scientific knowledge. But some indications allow us to speak of a paradigm shift in school science that favors a more complete construction of knowledge that we make available to students in teaching intervention. Today, teachers should be aware of the need to opt for the contextualization of learning, where the context marks or situates the knowledge that is worked on in class to facilitate the subsequent application of the constructed knowledge. People and students, in particular, do not use abstract logical reasoning, but rather activate pragmatic action schemes in cognitive activities. The skills that come into play to solve a problem are embedded in the context of the problem itself, that is, in its physical structure, in the purpose of the activity, in the existence of other people who collaborate, and in the social environment in which it has been posed. Referring to the field of chemistry, for urban students of the twenty-first century, it is clear that the importance of the factors influencing problem-solving skills will not be the same for all phenomena. A student cannot activate the same skills depending on the context, depending on whether they are asked: Why does hydrochloric acid attack iron?, Why does a candle burn?, Why is acid rain formed? or Why does a cake rise?

There are different options for contextualizing chemistry, but if we take the perspective of the culinary context, it is very useful to introduce chemistry in the classroom, including women's knowledge. The kitchen is a true laboratory with chemical substances, instruments, techniques, and processes. Chemical phenomena occur in the kitchen when cooking with eggs, milk, meats, legumes, in the preparation of sauces, desserts, and in the preservation of food (Solsona, 2003c). If we did not value women's knowledge, we would find ourselves in a situation parallel to a history class where historical processes and revolutions in different countries are studied, without mentioning women and without considering how women have occupied different spaces and times, at the same historical moments when men were performing other tasks. Today we try to go further, and understand that the education of future generations cannot be thought of only in terms of their professional future, but must also think about their education as autonomous individuals, in instrumental care, and in the autonomy of people.

5.4 Analysis of the Elaboration of a Scientific Text

In school science, language allows for the emergence of new explanations, naming observed relationships and the new entities that justify them. For the analysis of the texts, I have used the criteria of relevance, completeness, accuracy, volume of knowledge, and text organization. We had already used these criteria on previous occasions to analyze texts produced by students in class (Solsona, 2001b; Solsona & Izquierdo, 2003). The relevance of the text consists of analyzing whether the arguments globally have coherence and refer to the object of the explanation.

The second criterion, that is, the completeness of the text, examines whether a sufficient number of arguments are developed and explicit causal relationships are established in the text.

The third criterion is the accuracy of the text, which consists of observing whether terms are used appropriately in the scientific context or the culinary context, as appropriate. And if words are detected that we could say are used in a metaphorical sense. The fourth criterion is the volume of knowledge, which should be appropriate to the level at which the explanation is given. And the fifth criterion is the organization of the text, that is, the sequence of explanations.

Managing written texts in the science class requires special attention. First, sometimes students show surprise and reluctance to "write" texts in a science class. An easy text like "Preparing a jam" or "Mixtures and solutions for snacks," with a laboratory report structure, usually allows students to gain confidence… Despite this, Marta says in one of the final activities, "Another task we had to do is to develop scientific texts, which seems easy but is not so much." And Vero comments: "When we were doing the experiments, we spoke in colloquial language, but to make the conclusions, we spoke in scientific language."

After preparing the cake, the cottage cheese, and the caramel in the kitchen-laboratory, I proposed to the students that they write a text about "Chemical changes in the kitchen." I have already mentioned that, previously, the classes had already written a couple of explanatory texts about two experiments carried out in class. This means that the students knew the characteristics of the text they had to write, with an introduction, development, and conclusion. The students have also carried out a peer evaluation activity, with the corresponding evaluation criteria to improve the texts written for their classmates.

Justification is perhaps one of the cognitive-linguistic activities related to science learning that is considered more complete, in the sense that, usually, we consider that a well-justified response is synonymous with good understanding. It is not enough to memorize the definition of chemical change or the macroscopic and microscopic explanation of it. Sometimes, students write very detailed texts, but merely descriptive, and sometimes very brief texts, with much implicit information.

From the evaluation of the texts on "Chemical changes in the kitchen," carried out at the end of the didactical sequence with the five evaluation criteria mentioned, I have obtained the following data for analysis. Regarding relevance, the texts are relevant, as they all refer to the culinary experiments carried out in the kitchen-laboratory and argue them with their own knowledge of chemistry. A group of students attribute to the terms they use to justify the phenomena a meaning that fits scientific orthodoxy. For example, a student who writes a very brief text says: "In recent months, in the chemistry laboratory, we have done several 'culinary' experiments such as making cake, cottage cheese, or sugar and charcoal. It has helped us study some of the properties of substances and know the chemical changes that occur. We have learned a little theory and applied it to the production of food and the changes that occur in it, always working at the macroscopic and microscopic level. We bring the ingredients, prepare the materials, and in groups, we organize the experiments. We write down observations, conclusions, and difficulties, etc. At the macroscopic level, we have seen that in the formation of the cake, as in the cottage cheese, as in the sugar and charcoal, energy exchanges occur, and new substances with new properties are formed. At the microscopic level, we know that there are breaks in the bonds of the reactants, that there is atomic rearrangement, and that we obtain several products of the reaction." The text is incomplete, perhaps due to its brevity. It does not seem that the entity "bond" nor the principle of mass conservation are correctly constructed since it does not mention the formation of new bonds in the products of the chemical change.

Sometimes, the terms "new substance" and "property" are used as unique identifiers for chemical change. For example, a student simply says, on the one hand: "At the macroscopic level, we observe that from some substances we obtained new substances." And adds: "At the microscopic level, we learned that there was an atomic rearrangement, that is, bonds were broken and new bonds were created in the products." On other occasions, students tend to use scientific terms as if they were "labels" that they consider explanatory by themselves, without properly appropriating the meaning of the concepts or terms. For example, in justifying chemical changes, they use the concept of property in a non-pertinent way when they write: "In the formation of cottage cheese, a chemical change has occurred because the milk has new properties," "A chemical reaction has occurred when the sugar is carbonized because the result obtained has different characteristics."

In other texts, the student simply has not constructed the terms "substance" or "change of substances" and says: "It is a chemical change because it goes from being milk to being cheese. We made the cottage cheese with milk and a few drops of lemon and heated it. When it was hot enough, we filtered it, and the water that fell became whey that came out of the lemon drops."

In previous studies, we analyzed a text made at the end of a didactical sequence in a laboratory context for the study of chemical change. On that occasion, one of the problems detected referred to what we called the "meso level of explanation," that is, the confusion between "object" and "substance"; we said then that the confusion was due to the fact that eggs, yogurts, chocolate tablets, sponge cake... are "objects" that, during the chemical change process, acquire new properties attributed to new substances. Currently, with the didactical sequence in a culinary context, I have not observed this confusion.

In some texts, physical change and chemical change are confused. For example, to justify the chemical change process from sugar to caramel, with the formation of liquid and volatile polysaccharides, they say "The sugar has melted." It is true that sugar melts, at first, but there are students who use "melting" to identify the change of substances. In this sentence, it is also observed that the verb "melt," which has a precise scientific meaning, is used in another sense. In these cases, students can observe a piece of ice that changes state, sugar that dissolves in water, or an aspirin that reacts with water and in all three cases justify the phenomenon by saying that "it has melted," although in some cases (not always) the students clearly differentiate the three phenomena.

Regarding the second evaluation criterion, completeness, sometimes students have problems elaborating a justification because they do not select a sufficient number of reasons that give a global view of the chemical change and establish explicit causal relationships. To interpret a phenomenon, whether culinary or laboratory, different causes and consequences must be taken into account, and sometimes they only write some. Thus, for example, a group of students justifies the chemical change with a single argument, that is, they talk about atomic rearrangement without referring to the macroscopic level of substances. Other writings are not complete since the students repeat the experiment but forget to justify macroscopically and microscopically the chemical changes involved in the processes.

The elaboration of a justification is related to the construction of the entities and the corresponding characteristics of the reference theoretical model. Students who have constructed the entities related to chemical change, for example, the substances involved, the reactants and the products, the principles governing chemical change, the factors influencing it, etc., can construct causal structures with the appropriate entities and write quality texts. But a student who has not constructed these entities in a meaningful way may use the terms in a sense not established by chemistry. For example, a student says: “The heat makes the milk boil, and this makes it react with the lemon.” Another example would be: “When adding lemon to the milk, it boils because it heats up a lot.” In both cases, we can say that the girl does not clearly distinguish boiling from chemical change, indicating that the two entities: “boiling” a change of state and “chemical change,” where we obtain different substances from the initial ones, are not yet well constructed.

On previous occasions, we have studied the use of causal reasoning in the development of explanations by students (Solsona et al., 2000). In the introduction to the study of the chemical change model, in a culinary context, students use causal reasoning more frequently and spontaneously. In the culinary context, it is easier to identify actions than in experiments typical of a school laboratory, since many of the actions performed in the preparation of a cooking recipe facilitate the establishment of causal reasoning. In the three experiments carried out, heating is required, so the students, in their causal reasoning, introduce the causal agents typical of the culinary context: heat, culinary actions such as spreading and stirring, material agents such as lemon, yeast, water, oil, salt... For example, they easily recognize fire as a causal agent, and a student says: “The caramel is already made by the effect of the action of heat on sugar” and constructs a linear causal structure with a single causal agent, heat, which acts on an “element”, sugar, and produces an effect, caramel. A possible description of this causal structure is as follows:

acts on produces

CASUAL AGENT → “ELEMENT” → EFFECT

heat → sugar caramel

In a recipe for preparing sauce to accompany macaroni, she says: “In the cake experiment, saw the role of yeast on the cake dough. The action was to increase the volume of the cake. There was also an atomic rearrangement because at the end of the experiment we obtained a substance that was not the initial one.” In this case, the structure is linear, but slightly more complex since a single causal agent produces two effects. The description of this linear causal structure has the following form:

acts on produces

CASUAL AGENT → “ELEMENT” → EFFECTS

yeast → dough → increase volume, Atomic rearrangement and new substance

In justifying the observed changes in the preparation of cottage cheese from milk, a student wrote: “A change in structure has occurred because the substances that made up the milk, which were well mixed, change. We know this because the taste changes (cottage cheese is more acidic than milk) and also we can easily separate the cottage cheese and see that they are different substances. This happened because we added lemon, heated it a little, and the lemon reacted with the milk.” In this case, the causal structure is much more complex, as the student uses different causes and refers to different effects.

acts on produce
CASUAL AGENT → "ELEMENT" → EFFECTS
heat → milk, lemon → change in structure, change in taste and new substances could easily separate

It is interesting to note that, in the classroom context, a "good justification" has its own "rules of the game", which are different from those applied in other contexts. If a student justifies an idea by saying that it is stated in the book or their mother's recipe, we ask them to write in their own words what they have understood from the text they have read or the explanation we have given in class.

Sometimes, in the development of causal structures, they confuse or do not know how to distinguish the cause from the consequence. For example, in justifying the preparation of the cake, they say, "When the chemical change in the cake dough has occurred, a new substance is created, that is, it becomes more toasted and consistent," or to justify the formation of cottage cheese, they say, "It is due to the fact that its density has increased." Regarding the third evaluation criterion, precision, one type of difficulty refers to the use of scientific terms. In chemistry classes, we encourage the rigorous use of terms, but words are polysemic, and in everyday language, the same word has different meanings. Terms such as "model", "mass", "energy", "element", and others can be used with different meanings, but in the field of science, they only have one. Students tend to mix meanings, without giving it more importance or considering it problematic, and for example, they can write: "The sugar element is a compound because it is made up of three elements: carbon, oxygen, and hydrogen." Many times, the same scientific vocabulary evolves. A few years ago, the term "molecule" was used to denote the elementary particles of any type of substance, while currently, it can only be spoken of some materials – most gases and some solids and liquids – as being formed by molecules.

Regarding the fourth evaluation criterion, the volume of knowledge, there is not always a correlation between the volume of microscopic knowledge and the development of good explanations, which must link microscopic entities to culinary phenomena that occur at the "macro-meso" level. For example, a student simply says: "the preparation of the cake is a chemical change since its particles form a new substance." On other occasions, there is not a balanced relationship in the construction of macroscopic and microscopic entities. For example, another student explains the chemical change microscopically in detail, and says: "At the macroscopic level, we can say that there is a chemical change when adding lemon to milk and applying energy, which is why the milk coagulates. The products of this experiment are cottage cheese and whey. At the microscopic level, we can say that the milk coagulates because the bonds of milk and lemon break and new bonds are formed in the cottage cheese and whey". The student seems not to have developed the entity of "substance," nor that of "atom", and does not establish a relationship between "bond" and "atom."

Another student, simply says at the microscopic level: “There is a rearrangement and reorganization of atoms.” She has not constructed the entities: “bond” nor the relationship between “the breaking of the bonds of the reactants” and the “formation of new bonds in the products.”

The last evaluation criterion used for the texts “Chemical changes in the kitchen” refers to the organization of the text, which allows analyzing its global coherence and textual typology. To analyze the global coherence of the text, we distinguish several categories (Solsona & Izquierdo, 1997). We say that a text is globally coherent when all the entities mentioned are interrelated and interconnected. In the case that the connection does not occur, we say that the text has weak coherence. In this sample, there are no incoherent texts, probably because the writing was voluntary and the texts that could be classified as incoherent were not written. But there is also another reason for the absence of incoherent texts: the culinary context facilitates appropriation by the students of experiments they had never observed in the laboratory. We must not forget that it is their cake recipe, their ingredients, and their skills to achieve something that must be edible. In the previous study on texts related to chemical change in a laboratory context (Solsona & Izquierdo, 1997), we obtained 33% incoherent texts.

An example of a text written by a student with global coherence, despite not following scientific orthodoxy, is the following: “These last days, in chemistry class we have studied chemical changes in the kitchen, and to better understand them, our teacher made us carry out experiments to verify it. Most of these experiments were recipes, and during them, we saw that many chemical changes are in our daily life, such as making a cake or cottage cheese. To carry out the experiments, we formed groups, although some members did not agree to be in the same group with people they did not get along with, but this was solved by sharing a couple of experiments. Some experiments were more fun or involved more ‘work’ than others. But well, we cannot complain about what we have done, for example, for me the chocolate cake we made in our group was the one that gave us more work and at the same time the most fun to make. We did three experiments: cottage cheese, cake, and caramel.

The experiments have nothing special unless you look at them as we did, everything we have done are culinary experiments. They all have something in common, which is that they undergo a chemical change that occurs for different reasons, which is that, at the macroscopic level, all the experiments carried out start with some main substances, which in scientific terms are called reactants, and end with a new substance or substances called products.

In the chemical changes we have carried out, we have the reactants, which react with each other when energy is applied, and this causes the products to form. At the microscopic level, the three experiments have more things in common than we think, in all three new structures and different substances are formed from the beginning. They also undergo atomic rearrangement, which causes the atoms of the reactants to rearrange into a new substance. In the experiments, we have also been able to observe that there is an exchange of energy, which causes a chemical change. Another important characteristic is the conservation of mass, which all the experiments carried out have, but it is difficult to demonstrate since a small amount is always lost when changing the container or filtering. That is why the teacher always leaves us a small margin of error since she knows the problems of inexperienced people like us, who are beginning to delve into the world of chemistry.

In conclusion, we can say that each product is different since they all have their drawbacks, the only thing I can say is that I have enjoyed doing these experiments very much, and I only wish to continue doing them, as this is how my great knowledge and skills in the subject 'cooking' are manifested."

There are no cases of text constructed with juxtaposed or coordinated phrases without explicit relationships, that is, there are no texts with a weak structure in this experience. As for the textual typology, in the sample I analyze there are three purely descriptive texts. Five texts combine the descriptive part of the procedures with the explanatory part. One text from a girl combines the narrative part of the experiments with the explanatory part, forming three blocks corresponding to the three experiments. And six texts, from four girls and two boys, are explanatory with a final corollary or generalization. An example of a descriptive text from a girl says: "So far in our chemistry course we have done several experiments, but when we got to Topic 5 on chemical changes we did three. One of them was making cottage cheese. It is a chemical change because it goes from being milk to being cheese. We made the cottage cheese with milk and a few drops of lemon and heated it. When it was hot enough, we filtered it and the water that fell became whey that came out of the lemon drops. We calculated the mass of the reactor first and then measured the mass of the product.

After the cottage cheese, we did another experiment which consisted of making a cake, and in our group, we made a traditional cake. To make the cake, we mixed all the ingredients and put it in a mold and baked it at 180 °C. Our cake didn't rise much because it lacked flour and also, part of the mixture remained in the container where we mixed everything. But in the end, it turned out quite good and we ate it all. And the last one we did was the sugar one, which consisted of heating sugar and we could choose between making caramel or charcoal. When the caramel was made, it smelled very good and could also be eaten. But when the charcoal was being made, it looked like a monster breathing or an 'alien' and it was disgusting. These are the three chemical change experiments we have done and, I think they have turned out quite well and we haven't blown anything up and this means that it hasn't gone too badly for us."

The text classified as descriptive from a boy says: "In our 4th grade class, we have carried out various culinary experiments, to be more specific, three to check the different chemical changes that different substances had when mixed and heated. Next, I will explain what these experiments consisted of and the experimental difficulties we have had. The first experiment was to make cottage cheese. We were able to do it because we had the basic knowledge to do so. First, we prepared all the materials, then we introduced the milk and about ten drops of lemon into a beaker, having previously measured the temperature and initial mass. Then, we turned on the burner and recorded the temperature of the liquid and the characteristics that the milk was adopting every two minutes. After 10 min, it began to coagulate and we turned off the heat. In this experiment, we obtained, from milk and lemon (reactants), two new substances: cottage cheese and whey (products). The experimental difficulties that have affected the accuracy of the data have been the losses we have had in the filter paper when pouring it into a container, and we also had some cottage cheese residue on the thermometer."

Many times, students are able to answer the typical "school" questions from the manual or textbook, but when they find themselves in everyday situations they do not know how to transfer the learned knowledge, they do not know how to apply it. In the context of a basic education with a majority of students who will not continue scientific studies, it is important that they learn to justify daily life facts using scientific models, in the case of the experience that concerns me with the chemical change model. For example, in culinary processes, students can act and intervene in the transformation of materials by manipulating known substances, so that they are talking about phenomena closer to their lives. The game of "seeing and speaking scientifically" about everyday facts is stimulating for most and encourages, in the case of giving explanations of the observed changes with reference to the chemical change model, that they develop balanced justifications between the macroscopic and microscopic levels, one of the central objectives of scientific learning, at the initiation levels of chemistry. Thus, in the preparation of the cake, a significant group of the class is able to write a recipe like the following: "We break the eggs, add the sugar and stir. We add the flour, the milk, yeast, and lemon peel. This is a physical change, a mixture. At the particle level, there has been no rearrangement. When baking the cake dough in the oven, there is a chemical change since new substances have been formed, the cake and the gases that make it rise. There is a rearrangement of the atoms of the ingredients due to the heat of the oven."

Regarding the titles of the written texts, two girls agree with the one proposed by the teacher: "Chemical changes in the kitchen." The other girls write titles of the following type: "Let's be cooks in the laboratory," "Culinary practices in the laboratory," "Chemical changes that unknowingly we can find cooking," "Cooking teaches chemical changes," and "Report of the experiments we have done to explain the chemical change." In the case of the boys, two boys present the written text without a title, and there are three texts with the same title proposed by the teacher: "Chemical changes in the kitchen." The rest write: "Chemistry in gastronomy," "Chemistry in the kitchen," "Chemistry in the kitchen? Why not?", "Our culinary experiences in the Institute's kitchen," "The best chemical changes in Josep Pla's kitchen," and "The studious cooks of Josep Pla."

5.5 Analysis of the Results and Continuity of the Didactical Experience

After 5 years of experimentation (Solsona, 1999, 2010a, 2012a, 2015a), I can affirm that the initiation to chemistry in a culinary context is an innovative and successful educational intervention, which allows working with very promising didactical orientations. These are the ones that refer to the consequences of the actions that appear in the recipes and those that follow the trail of a substance in the different “states of the object”: for example, powdered chocolate and chocolate in a colloid like hot chocolate, granulated sugar and sugar in the cake dough... Also interesting is the relationship between “change” and “composition” and the distinction, which is established with sufficient clarity, between “mixture” and “chemical change” in the preparation of the cake. As for the elaboration of explanations, indeed, we have managed to make the students “explain” and “act” by intervening in the transformation of substances, and this seems very positive to us. Very few times is this achieved in a chemical laboratory context, since students cannot intervene autonomously in the chemical phenomena shown to them and are not able, either, to “speak” and write justifying texts about them.

During the 5 years of experimentation in the culinary context, the composition of the classes in terms of the percentage of girls and boys has been changing. In the 2000–2001 academic year, the composition of the three classes of fourth grade of ESO was very balanced: 47 girls and 44 boys. Although the female students were brilliant, there was a group of very academic boys who did not lead the functioning of the classes but set a more strictly laboratory context and a type of questions more oriented towards theoretical aspects. In the 2001–2002 academic year, the composition of the three classes was unbalanced: 42 girls and 27 boys. The female students were by far the best students, and there was no group of boys who stood out in learning, but rather stood out in their bad behavior. I can say that the classes had a clearly more feminine atmosphere than the previous year (Solsona, 2008a, b).

During the 2002–2003 academic year, the composition of the classes was balanced in terms of the number of girls and boys, but they were the best students, the ones who took the initiative in classwork and quickly reached consensus with the boys on the culinary preparations to be carried out. Finally, in the 2003–2004 academic year, the proportion of girls and boys has been different in each class. The two classes that have worked best have been those in which the girls are the best students, and although they are not the only ones to take the initiative, since in both there are also boys with good academic results, a good working atmosphere has been created around the culinary context, with ideas, comments, and even exchange of recipes among the boys, outside of school hours, individually. The class that has not achieved such good results is characterized by being led by a group of boys mediocre in academic results and in which the good female students adopt a passive role in group work.

From the perspective of educational research, the analysis of a scientific text written after having carried out the three experiments has the added value of the time that has passed, 1 month, since we discussed the first experiment in class. The memory of the analyzed scientific facts and the scientific justifications developed by the students is not immediate nor is it a repetition of the phrases said by the teacher, more or less from memory. The content of the text “Chemical changes in the kitchen” is a reflection of the overall vision and the stage at which the process of constructing the chemical change model is found by the person who writes it. The breadth in the diversity of theoretical models of chemical change constructed ranges from some students who have not been able to write any text on the subject, which allows me to think that they do not even have a precursor model of chemical change, another group of students who are merely descriptive, understood as a change of substances where the terms reactants and products have been incorporated, to the four girls and two boys who have developed explanatory texts with a corollary or final generalization. This group is the one that has developed a more complete model of chemical change, with a balanced justification between the macroscopic level of substance change and the microscopic level, for the corresponding learning level.

Regarding teaching instruments, laboratory reports or heuristic 'Vs' are very useful tools for learning and evaluating students' strictly scientific learning. But if we take into account feelings and affections in a broad sense, and their impact on the learning process, the texts written by girls and boys provide us with more information. The general opinion in the class is that the preparation of cottage cheese "is not difficult, but it is very specific", the cake "is more complicated" and the sugar one "is the simplest".

From a competency perspective, in kitchen chemistry, the three types of knowledge that define any competency action are combined: knowing, knowing how to do, and knowing is a being and being. Knowing is identified with the logic of concepts that establish implication relationships between them and allow for a timeless conceptualization: substance, chemical change, etc. Knowing how to do corresponds to the logic of action that favors the establishment of causality relationships and conceptualization in the learning context: preparing a cake, choosing and preparing the ingredients for a snack, etc. And knowing how to be is an essential learning for citizenship in today's society with social justice: being interested in culinary preparations, sharing learning with other people, etc. (Solsona, 2010a).

One possibility for the continuity of the experience is to carry out small research projects or work projects on topics related to women's knowledge and experience, such as food preservation, substances and instruments in the domestic sphere, chemical changes in the kitchen, etc. (Solsona, 2012a, 2015a). An approach closer to new research fields and new university degrees, such as food sciences, health sciences, ecology, than the traditional physics, chemistry, biology, and geology that continue to be studied in secondary education. In addition, until now I have worked with the culinary context and the substances present in the preparation of some very simple dishes. In future research, we will have to work with cleaning products, which contain substances such as ammonia, chlorine, formaldehyde, or chloramine.

Today, teachers have external support to develop the task of seeking different learning contexts. For example, on television, they make a cooking program for inexperienced young people, in Barcelona, at the Science Museum, a series of talks on "Science and Cooking" was held, in a Municipal Market there is a Cooking Classroom that develops "Cooking Workshops for Children", where they observe, dissect, touch, knead, and taste any food and prepare a recipe. In addition, we have information on web pages of some experiments and research related to the chemistry of everyday life, such as: or directly with the teaching of cooking as: The analysis of food from bromatology at and to consult the ingredients of different menus, their energy value, and a balanced diet, a possible address is: http://www.farmaceuticoline.com/.

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Chapter 6
Chemistry for Citizenship

Mercè Izquierdo Aymerich

6.1 Introduction

Chemistry teachers around the world teach more or less the same thing. The books at all levels of education (and in all countries) are very similar, too similar. The "topics" are the same as always, those that have been imposed since the 1960s, over 40 years ago: the atom (various models), stoichiometry, the Periodic Table in relation to electronic configuration, the three types of bonding, thermodynamics, chemical equilibrium, acids and bases, redox reactions and batteries, a bit of organic, some descriptive of the TP groups… (Bennet & Holman, 2002). They are illustrated to adapt to the age of the students they are aimed at and include examples from everyday life or related to modern technologies or relevant social events, but this does not significantly change the content.

There are indications that science education (and chemistry in particular) is in crisis; for example, there is a shortage of teachers with knowledge of chemistry for primary and even secondary education, and the number of students in science faculties is decreasing. It is very difficult to teach chemistry to "non-chemists" (geologists, veterinarians, environmentalists…) who cannot relate it to the topics that interest them; and, even more so, to children who are not willing to make titanic efforts to memorize imposed knowledge that will no longer give them the "status" that was once associated with "knowing chemistry" and that, on the contrary, arouses suspicion because it is related to environmental pollution. Despite all this, although the achievements of chemistry are increasingly spectacular and, overall, its

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contributions to culture are original and creative, disinterest in it has grown in large sectors of the population.

Simultaneously, secondary education has begun to be mandatory for everyone, and new approaches have been promoted: "chemistry for the community," "chemistry in context" to seek new ways of connecting chemistry and citizens, which have generated new curricula where cross-cutting themes acquire great importance. Air, water, soil, energy are studied… however, it gives the impression that this change in focus is relegated to the first years of secondary education, to non-chemical generalist teachers, and does not affect the deep convictions of specialist teachers, who continue to see chemistry as a dance of atoms according to laws derived from an internal structuring of matter that, from the students' point of view, is illogical, far removed from common sense… and from the chemical phenomena themselves!

This contradiction between the good intention of ensuring that the entire population knows chemistry and the reluctance to learn it, manifested both in school and at university, poses a challenge. It makes no sense to consider that people are wrong and chemistry teachers are not because chemistry will continue to lose its audience, and this is not what we want. Nor will we deceive ourselves by pretending to teach chemistry if what we do is play with chemistry to entertain students. The challenge is to connect the interests and educational purposes of citizens with those inherent to chemical activity (which must be both experimental and conceptual) and design new programs following this orientation and not the sequence of topics typical of traditional chemistry books. This need for change has been widely documented (Caamaño, 1999, 2001a) and textbooks have already been written with interesting contributions from history and based on students' experimental activity (Caamaño, 2001b) (Hart et al., 2000).

In the different sections, I will develop this issue and present a proposal for programming the teaching of chemistry, somewhat ambitious in its intention to promote chemical activity in compulsory education and also valid for university teacher education. This proposal is consistent with the "assessment of scientific thinking competencies" introduced following the recommendation of the OECD (1999) (EURYDICE, 2002). First, the overall structure of this proposal will be reviewed from the perspective of science education. Second, elements of an emerging "theory of school content" will be used to guide the task of "teaching science to all," considering that, to successfully achieve this goal, it is necessary to coordinate the learning that takes place in school and that which is promoted outside of it, through museums, media, and telematic programs. Finally, a curriculum proposal for introducing chemistry is presented, in which relevant situations pose problems and chemical entities are introduced to solve them through a modeling process. This programming provides, at the same time, a different approach to the university chemistry learned by future chemistry teachers.

6.2 Contributions of Science Education to the Design of New Sciences for Citizenship

The expansion of secondary education to broad sectors of the population to the point that in some countries, compulsory education is already being discussed up to 18 years of age (in Spain, it is already compulsory up to 16 years) is excellent new, but surprisingly generates failure and discontent among many young people who do not want to be in school for so long and are not interested in the knowledge taught there. Chemistry is considered difficult, and therefore it is hardly taught in primary school, and few students choose it in secondary school and at university, consequently disappearing from programs, which also reduces the number of specialized teachers at basic education levels. One of the reasons may stem from a certain lack of definition in institutional discourses, in which, when proposing the purpose of teaching science to the entire population, they speak of "scientific literacy" and, although it is now clear what "literacy" means (teaching to read), it is not when the adjective is added. Does it mean that we have to teach reading scientific texts? If so, is it possible to do so? Does it mean that we have to teach the ABCs of science? If so, what should be taught?

It is necessary to start by clarifying this point, but it can be anticipated that the programs to make everyone literate in chemistry cannot be the current ones, which were thought for something completely different, and that the chemistry of formulas and atoms contributes little to a basic scientific education. Those who should promote this critical reflection on the programs are the teachers themselves, since they know the school and the new demands or needs of their students; but for this they face the realization, very difficult to accept, that very little of what they learned will be necessary for today's students, who do not intend to be chemists like their teachers.

This goal (teaching chemistry to everyone) is raised for the first time in history and perhaps what makes it difficult to move towards it is that we do not believe it is possible to achieve it. Until very recently, it was assumed that everyone had to learn to read, write, and perform the four arithmetic operations (add and subtract, multiply and divide) as well as some "general culture"; and teachers were in charge of teaching it. The "specialist teachers" appeared in secondary school, they had trained in a discipline and their teaching was strongly influenced by the explanatory ideals of the discipline. What is being asked now is that these specialist teachers select the basic disciplinary knowledge both to be able to continue studying in the future and to provide everyone with the necessary scientific knowledge to interpret their environment and make decisions about their own health. They should not be guided by the explanations of "their" discipline, but by the explanatory/educational ideals that are set as the purposes of basic education, and they must adjust their programs accordingly. This task is very difficult and can only be successfully carried out by teachers who contemplate their discipline from the perspective of having to teach it in such a way that students (those who reach real classrooms, not ideal students who should adapt to the usual disciplinary programs) learn and are able to give coherent explanations of the phenomena of the world according to the various sciences. The knowledge of teachers capable of this reflection is what constitutes the new discipline of didactics of science, and thanks to them this new field of knowledge develops and advances (Fensham, 2004).

Thus, “didactics” is not an adjective that applies to a fortunate presentation of knowledge to students, but a noun that denotes “the science of science teaching “ and that does not commit a priori to the traditional contents of textbooks, but can overcome them to respond to new educational demands such as those that are now occurring and generate new proposals that are both scientific and effective for everyone. To do this, it is necessary to start from as deep a knowledge as possible of a discipline and its connections with others that are related to it; from the expectations and abilities of students; and from the purposes of compulsory education, to invent new topics and new teaching interventions that will require new forms of evaluation (Aliberas et al., 1989).

It is evident, as numerous researchers in didactics of science have argued, that the topics of this school science must be those that until now appeared as cross-cutting topics: environmental education, health education, understanding of the technological devices most present in everyday life... And that the contributions of science museums, cinema, multimedia, the Internet, etc. must be taken advantage of. On the other hand, other voices warn of a possible superficiality of these approaches, which can lead to new descriptive sciences, although now they are of “the practical” as before they were of the conceptual. It is time to decide on many new contributions that seem incompatible and that at this moment even paralyze or reverse important reforms that were already underway.

We now have theoretical foundations (from didactics) that facilitate the work and guide the path to be taken towards the established goal, literacy in chemistry. It is necessary to show, first of all, what chemical activity consists of, reproducing it as much as possible in class (Izquierdo et al., 1999a). Only in this way will chemical entities (atoms, molecules, formulas) come to have meaning for interpreting experiments in which students can genuinely intervene. This path must continue towards other goals, specific to higher levels of education, and therefore must be designed in such a way that the path does not have to be retraced at any time. If it has started by promoting understanding and decision-making, it must continue in the same way, without returning to an excess of information if it cannot be applied.

Based on what has just been presented, a science program for citizenship must plan both the theoretical, experimental, and linguistic aspects (what can be thought, what can be done, what can be said) so that, together, the fundamental ideas of science are learned thanks to a coherence between these different dimensions of cognition (Guidoni, 1985). And this can be achieved if the class is presented as a “discourse” aimed at transforming ideas, by acting according to the rules of chemistry and by speaking reflectively about what is being done and thought. For this, students, teachers, and the knowledge of textbooks must interact (Sutton, 1996; Jorba, 1998; Rowell, 1998; Marquez et al., 2003).

The design of “science for citizenship” requires exploring the different dimensions of content, which go unnoticed when the argument of authority prevails, that is, when they are selected by tradition and because it is imposed by the academy. A new approach is required. The objective of the activity we want to promote is the intellectual formation of the student, which can be achieved thanks to the problems and challenges of chemistry; and we must structure and evaluate it with didactical criteria (Justi & Gilbert, 2002). The product of our design will be school chemistry, something unprecedented (Izquierdo, 2013) that must contribute to students learning to think for themselves and being able to make decisions consistent with their life project.

6.3 New Content for New Purposes

The need for school science to be meaningful has led us to highlight that scientific knowledge is not "in a book" but is a human activity of intervention in the world with certain characteristics, which are the ones that must be taught. The introduction to chemistry is one aspect of this activity that will be promoted in class and that, when maintained throughout the levels of education, should culminate in the scientific thinking skills desired for the entire population.

Teachers sometimes justify students' learning difficulties due to the intrinsic difficulty of science: because "they deviate from common sense," as if it were a merit of science. If chemistry is to be "lived," this supposed goal (to distance our students from common sense) loses meaning. It is true that the theoretical statements of chemistry and its language do not seem "logical," but they are when viewed from the perspective of chemical activity: they are the most suitable for what is to be achieved and, therefore, are common sense for chemistry, although it may not seem so when trying to put them in writing in a text that develops without practical references that, not being explicit enough, seem secondary and give prominence to entities that seem very strange when taken literally. We believe, therefore, that school chemistry must be "reasonable" in addition to being rational (Aliberas & Izquierdo, 2004). To do this, it must take root in experiences of chemical change, in relevant situations in which it has been possible to intervene, think, and talk and write about using meaningful languages (Gardner, 2000).

According to White, the contents that give rise to experiences present certain "dimensions" that can be addressed with the theoretical and practical resources currently provided by the DC (See the table, Izquierdo, 2004).

With seriousness and rigor, the topics should be organized around the basic and irreducible "models" (Izquierdo et al., 1994) that allow for the interpretation of sets of phenomena that are relevant to the education of all individuals, which must be identified, selected, and reworked (Black, 1986). And these basic models are neither the most modern nor the most ancient; they are the ones that group the ideas that underlie the knowledge derived from a specific educational intention that includes teaching reasoning in the manner of the physical and natural sciences.

From Table 6.1, we can establish the "elements" that must be taken into account when choosing the topics of school science, which are related to and conditioned by each other. (White et al., 1994), These elements of "what to teach" that I select are

Table 6.1 New dimensions of content that can be developed from current contributions in science education

Overture to common experience	Having preconceptions
Accept the presence of common words	Prioritize communication through everyday language before introducing scientific terms
Take into account that students use alternative models with explanatory power	Develop scientific argumentation in the classroom to support the process of scientific modeling
Complexity	Work in three dimensions: do, think, communicate
Must be able to evoke emotions	Connect with the motives that make students want to learn and develop metacognitive processes
Require social acceptance	Must connect with an educational purpose that has consensus
Abstraction	Organize school activity based on Theoretical Models or Structuring Ideas
Must be demonstrable, not arbitrary	Use a science model of "moderate" realism and rationality
Must be able to connect with other knowledge that will also be learned	The basic and irreducible ideas must be structured to continue learning
Always a mix of different knowledge	Take into account multiple intelligences and design different access and progression paths

familiar to us, but I believe that based on what has been reflected upon so far, they take on a new meaning and invite us to act more radically:

- The educational objectives or purposes, which provide the emphasis of school science.
- The thematic cores, organized around the theoretical models, with their access routes and their structuring knowledge.
- The justification processes, with their progression routes for the construction of paradigmatic facts.
- The criteria for connecting with knowledge from different disciplines, recognizing new knowledge that can be connected with what is already known, and identifying those that should be left for another time.

Let us look at it in more detail, starting with a concrete example of programming school chemistry.

6.4 Proposal for a "Chemistry for All"

We will apply the ideas that have been presented in the previous section to propose a "Chemistry step by step"[1] (Izquierdo & Merino, 2008) for teaching chemistry to primary school teachers. It is a chemistry for everyone, consequently. The

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[1] In Spanish, "Química paso a paso".

peculiarity of this program is that it does not actually intend to introduce the discipline we call "Chemistry," as presented in current textbooks, but rather aims to develop "chemical activity" in the school guided at all times by chemical theoretical thinking. This proposal concretizes and develops the ideas presented in Izquierdo et al., 1999a, 2003. In Izquierdo, 2013, the theoretical foundation of school chemistry is deepened in a cognitive model of science and in the history of chemistry.

Chemists (not "Chemistry") have developed an Atomic Theory that has become "the theory" with which they explain the control of material change, the design of new changes, and the obtaining of new materials with specific properties. It begins by showing what the atoms of the elements and the formulas of their compounds are like, and from there, the chemical behavior of all materials is deduced. But this theory only makes chemical sense when chemical activity is carried out, to guide it and to understand its results. We must begin, then, by introducing ourselves to it, by sharing its objectives, as we have seen when referring to the contents of school science. It is possible to do so because, although "Chemistry" is a sophisticated and abstract construction that apparently moves away from common thinking, chemical activity is a dimension of human activity inherent to all people and all cultures. Let's see what the "Chemistry step by step" consists of, following the scheme proposed in the previous section.

6.5 The Objectives (History of Personal Science)

All human activity must be autonomous and must have an interesting purpose and a specific motive that drives it. Scientific activity has a dual dimension, being both practical and theoretical at the same time. It intervenes in phenomena, guided by the specific objective to be achieved. At the same time, it builds a conceptual structure that ultimately constitutes a "corpus" of knowledge. School scientific activity also has these two dimensions. Since it takes place in the school, for these purposes and motives to function, they must be compatible with the educational purpose of the school, as perceived by the students; and, as the school is now, this purpose is the obligation to pass the course. And this is not convenient for us.

The main difficulty that the school environment can pose to school scientific activity is the disconnection between levels and subjects; students do not perceive the continuity of the process, since there is none, and they do not experience the challenge of acquiring new skills in understanding and interpreting new chemical phenomena. The approach proposed, "Chemistry step by step", and whose name tries to reflect, is that the teaching and learning of chemistry are presented and developed as a school science with history that develops year after year according to a sequence that is both "interesting intervention" and "coherent conceptual construction."

Therefore, it is necessary to foresee what needs to be known, what needs to be "written," represented, said, the problems that will be posed, and those that can be solved to propose a progression strategy that provides rhythm to learning (for example, establishing a "learning cycle" with different stages: explore, introduce, apply).

The difficulty of this approach cannot be hidden, which, however, is the condition for students to enter the game of "rational" control of changes and develop a "chemical activity" in school. A class management is essential in which priority is given to communication between students and teachers, group work, and formative assessment (Jorba & Sanmartí, 1996). For this to be possible, school chemistry must have a "chemical theory" (identifiable in the designed curriculum) that can be developed by elaborating examples of a Chemical Change Model at the pace of the practice of chemistry by students.

6.6 The "Thematic Cores"

The curriculum topics must be linked to the Theoretical Model "Chemical Change" and must contribute to its development in its different fields of application; these topics introduce the structuring knowledge that gives meaning to concepts such as energy, equilibrium, structure, change. . . which are applied and measured differently in the other Theoretical Models of the curriculum.

The "Theoretical Model" is crucial to ensure the theoretical and disciplinary foundation of school chemical activity. Manipulating materials and being able to say what happens when changes occur is not yet a chemical activity. What characterizes it is the ability to think about them considering them "chemical changes": identifying the relationships between them and explaining them in the manner of chemists. Chemistry cannot be learned by learning definitions about substances, atoms, bonds. . . or learning formulas and equations, but rather by learning to see, in changes, what makes them chemical and what we call the "Chemical Change Model" (see Merino & Izquierdo, 2011). As changes are analyzed from this perspective, their specific variables and magnitudes are identified, chemical entities are introduced, explanations and definitions are elaborated; the concrete changes in which they have intervened become "paradigmatic examples of Chemical Change" and what they all share constitutes the Chemical Change Model, which adjusts to the specific cases in which they have intervened and which is explained by the entities that are assumed to define it (Estaña, 2001).

R.N. Giere (1988) represents the "cognitive model of science" that he develops and in which we are inspired by the scheme in Fig. 6.1. It can be considered that all chemical science has developed according to this scheme, based on objectives and action rules to achieve them that are shared by the community of chemists and phenomena that are considered representative of this action and these objectives. New phenomena are incorporated into the Model, and some are rejected; the Model becomes robust and creates its own language and new objectives.

It can be considered that chemistry has developed according to this scheme, based on objectives and action rules shared by the community of chemists and a collection of phenomena that are considered representative of this action and these objectives.

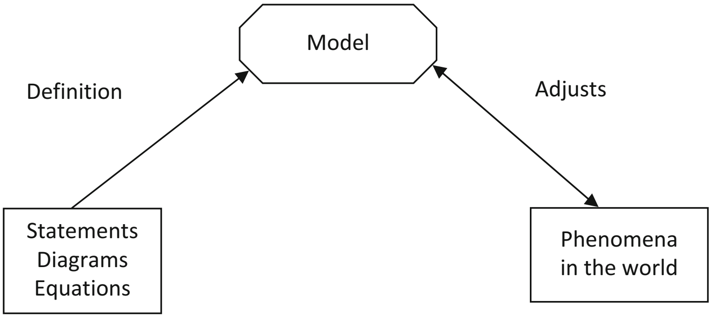

Fig. 6.1 The model can be defined using languages appropriate for school activity. (Adapted from Giere, 1988)

Over time, new phenomena are incorporated into the Model, and some are rejected; the Model becomes robust and creates its own language, instruments, and new objectives (Kuhn, 1993).

School science does not work this way because its objectives are different and the knowledge that will emerge is already designed by the teacher, but it develops according to similar cognitive processes. An initial representative phenomenon is also required (which will be specific to school chemistry) in which the rules of activity according to the Model are established and made to work. In our proposal, the phenomena that articulate the curriculum correspond to three different "approaches" that chemistry uses.

First, we introduce the reflection on fire, experimenting with combustion, with the candle and the formation of charcoal by thermal decomposition of wood. The ideas that allow this first outline of CQ are: the disappearance of some substances and the appearance of new ones; the conservation of mass due to the conservation of elements; the identification of invisible substances (oxygen, carbon dioxide) by the variations of mass that are measured; the fixed proportions in chemical changes that allow assigning a chemical mass to the elements (Solsona, 1997). The notion of a chemical atom emerges, along with some symbols and formulas of a few atoms (of atmospheric gases and water) that represent molecules.

Secondly, we focus on water and its "elements", hydrogen and oxygen, which will represent "chemical opposites" as the cause of chemical reactivity. It is now relevant to refer to the electrical nature of matter. The electrolysis of water is now the central experiment; the chemical reaction is linked to electrons, the atom becomes complex. The conductivity of some solutions requires new entities, the ions. Acid-base reactions and precipitation reactions are interpreted from this new perspective. New substances and formulas are known (which present the regularity of the compound name that reveals their ions): salt – sodium chloride and others similar, and the "mysterious" transformations of hydrogen carbonates and metals, so important in chemical equilibria in organisms and in the sea. We reflect on the energy changes in CQ from the electrochemical cell, an "invention" as simple and revealing as the candle had been.

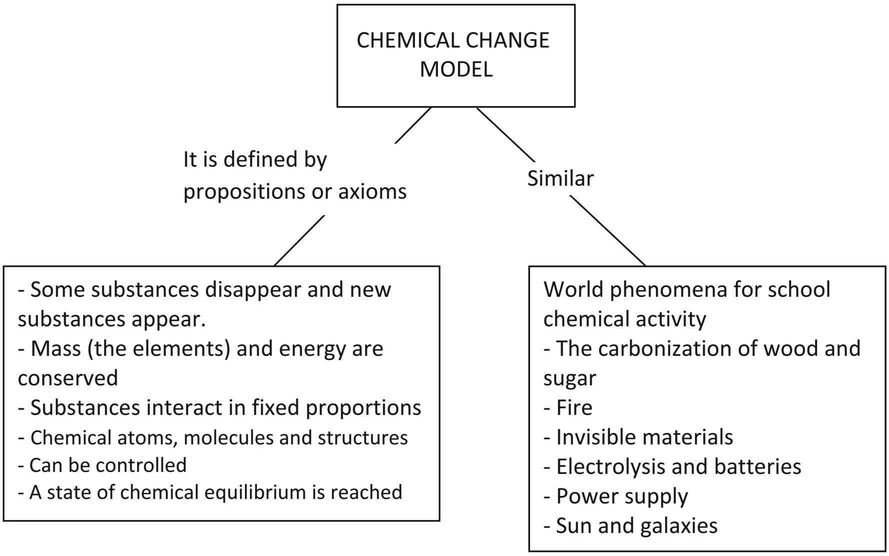

Fig. 6.2 Phenomena in the world become "chemical changes" when they coincide with the theoretical model of chemical change

Thirdly, we deal with chemical changes in the kitchen, which lead us to think about chemical changes in living beings. The new entities are now macromolecules. The properties of substances and their mixtures suggest structures and lead us to bonds. Photosynthesis deserves special attention, as well as the consideration of energy utilization in the combustions that occur in cells.

We represent our model of chemical change through the scheme of the following Fig. 6.2.

6.6.1 The Justification Processes with Their Progression Paths for the Construction of Paradigmatic Facts

For a genuine activity (AQE) to take place, one must "enter a 'History', something that is lived and can be narrated", with its introduction, intrigue, development, and conclusion. This story cannot be the one that has as protagonists entities that cannot be identified in the world; these "atom stories" do not evolve, have no intrigue or development, nor end; from the beginning, they are already definitive and compact.

The alternative is to live an intellectual adventure that can develop throughout classes and courses. As suggested by the scheme in Fig. 6.2, there are many stories to explain and that can become more and more interesting and complex as work progresses.

Let's look at some of the phenomena of the world that will be "exemplary or paradigmatic" as a result of school chemistry activity (AQE):

- Carbonizing sawdust, operation of old charcoal kilns in the mountains (constant mass relationships before and after heating, elements and simple/compound substances).
- Burning iron/oxidizing it under a test tube with moist air (constant relationship between the volume of air before and after oxidation, interpretation based on the general law of perfect gases, meaning of R).
- Representing the increase in mass of iron using screws and nuts, differentiating combined oxygen from oxygen in the air (concept of "amount of substance", of molecule and of mol).
- Chemical interaction "drop by drop" (ordering solutions of HCl and NaOH according to their molar concentration).
- Recognizing substances from their interactions, recognizing interactions from the identification of substances (chemical properties as a reminder of already characterized and classified reactions).
- Burning a peanut (constant relationship between the peanuts that burn and the energy that is transferred and interpretation in terms of bonds/chemical interaction).
- A battery with lemon and two metals, obtaining tin through electrolysis (NEM, the Faraday and the notation using ions with different charges, taking advantage of spontaneous changes).
- Eating a peanut (reflection on nutrition and the chemical basis of life/metabolism, based on various information).
- Representing chemical properties through objects and bonds that form three-dimensional structures.

All these stories/action projects will have the same protagonists: materials and their changes; atoms will also appear, but their role will be humbler, and the way of talking about them will evolve. They are structured as follows:

An initial narration introduces the topic in the appropriate context according to the Chemical Change Model approach.

From it, episodes emerge that lead to a deeper study, which includes experimental evidence.

With this, paradigmatic facts are constructed, which are the phenomena that can be explained through the entities that have been introduced in the modeling process and that is already an example that enriches the initial Model and that can also function as a model to interpret other similar phenomena (Estaña, 2001, 1996).

The new events or episodes that students face must be coupled to the MCQ thanks to the experimental activity guided by good questions that serve as "hypotheses". If the intervention in the new phenomenon manages to connect it with the "story of chemical change" that is being narrated through new entities, these constitute new languages necessary for that new episode (ions are necessary to explain certain experiments, macromolecules are necessary for different episodes) (Fig. 6.3).

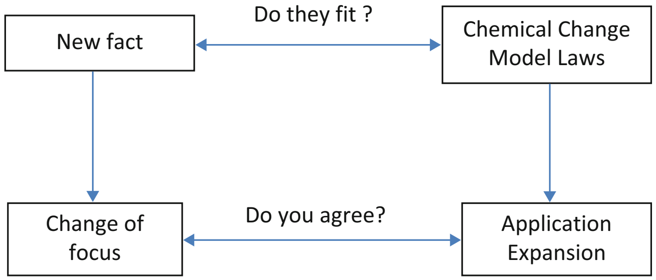

Fig. 6.3 Scientific modeling process (based on Giere, 1988) based on students' hypotheses

Theoretical hypotheses develop the story and are part of the intrigue, so they must be formulated as a forecast of what will happen "if... then... because..." "Since we have... then..." overcoming naive causality, based on a single variable and thinking in terms of the Chemical Change Model that is strengthened as it allows linking the various changes that are being known (see the "teachback" process in Aliberas et al., 2017 and Aliberas et al., 2019).

As already mentioned, students will not be able to perceive that their knowledge evolves throughout the courses if the teaching proposal does not have unity and, at the same time, a clear proposal for development throughout the levels of education. Each course, each level, must develop its own stories, always new, but always revolving around the same problem: Chemical Change, which is becoming increasingly familiar.

6.7 The Criteria: How to Evaluate School Chemical Activity?

To structure knowledge, it is necessary to recognize which ones are important, which ones are related to others, which ones are incompatible or irrelevant, and how to connect with new knowledge, in order to continue learning, to select more relevant information and reject what is not. Comparisons between phenomena, which are important and necessary to develop the Model, can lead to confusion: appearances deceive, one must go deep, criteria must be acquired to support the knowledge that is being acquired. Therefore, we propose a new evaluation style appropriate to the new purposes of Chemical Activity in SchoolAQE, for everyone. Since the proposal is to develop "chemical activity" with which the understanding of an increasing number of phenomena is developed, the evaluation must focus on the ability to intervene in phenomena and talk about them with the language of chemistry.

The guiding thread of the proposal is the development of competencies, and these are evaluated through global activities, in which thinking, experimentation, and language coincide. We believe that "the stumbling block" is experimentation, through which phenomena are intentionally intervened and thanks to which a living experience of what chemistry is and what is intended with it is acquired. Consequently, the programming proposed here (our "Chemistry step by step") will focus on what children can do, think, and communicate throughout their compulsory education. The "exams" are unprecedented experimental activities that students must solve.

6.8 Some Final Thoughts

The changes that have led to the new "information society" have modified the concept of "knowledge", moving it away from the "content of a book" and bringing it closer to "competent activity". With this, we must review the transmission of chemical knowledge that has been learned at the university in this specific disciplinary field at elementary teaching levels.

We realize that a "new school chemistry" is needed that is rational and reasonable for all students, also for those who will never be chemists. Because it is not rational when students are examined through a test of two hundred questions that require having learned by memory to solve routine exercises; or when students do laboratory practices corresponding to the "chemistry of the mole" when in class only they.

They talk about quantum mechanics. It is not reasonable when the problems presented to students are not very problematic and they are taught how to solve them until they internalize a routine that few understand well.

This new chemistry for everyone (a step-by-step chemistry that fits in with the other sciences in the curriculum) is the result of two previous decisions: one of them, with a broad scope and wide support from administrations, is to orient teaching towards the acquisition of competencies; the other, specific to didactics of science, is to provide school science with an appropriate epistemological foundation to design a school activity that is rational and reasonable and, as a result, scientific.

This is added to the new goal of teaching chemistry to all citizens, with the intention of teaching chemistry so that knowledge contributes to their understanding of the functioning of nature, their body, industry… with which it is necessary to teach "more than chemistry". We will need large doses of generosity and humility to follow this path: generosity to make our knowledge compatible with that of other disciplines and with a new purpose (educational); humility to recognize that there are many things we do not know (because we face phenomena that are not part of our previous studies) and that the new stage we are starting poses many doubts and because it is difficult for us to work in groups and recognize our ignorance.

According to the theory of school content to which I have referred, the topics of a new competency-based curriculum must refer to an activity, not to "pencil and paper" concepts. We believe that the best way to do this is by presenting "chemical narratives" and trusting that the good pedagogical judgment of chemistry teachers will allow them to foresee the didactical activity derived from them, their didactical potential; and letting teachers take advantage of them.

We have a long way to go, but the difficulty that may arise is more than offset by the joy of facilitating the understanding of chemical change for all people, which is essential to make sense of the world around us.

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Chapter 7
Reading in the Process of Construction of Scientific Models

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7.1 Introduction

Reading is one of the cognitive abilities most used in the classroom to promote the learning of sciences. Traditionally in science classes, the textbook was one of the main resources for students' scientific models' progression. However, for some time now, new textual typologies have been introduced in the classroom: from popular science articles and books to materials made by teachers specifically for students, texts from the Internet, and also fiction or narrative texts. The introduction of these typologies responds to the consideration that students must learn to make sense of a wide variety of texts (Shanahan, 2004) in the broad diversity of science readings available in books, magazines, novels, newspapers, and the Internet (Wellington & Osborne, 2001).

Despite the importance of reading in science classrooms (Martins, 2004; Marbá Tallada et al., 2005) and the generally low reading comprehension of students (as evidenced in the OECD's PISA reports), little research has been conducted to understand the processes involved in learning from science texts.

In this chapter, we will discuss the reading of texts used in science classes. Reading text could only be a meaningful task when it is part of the set of activities that take place in the classroom. From this perspective, we consider reading as an interactive process between the text and the reader (Yore et al., 2003), in which the mental representations constructed by readers are the result of the structure of the text, the reader's prior knowledge, but also the experiences present in the

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sociocultural context (Gee 2000 cited in Yore et al., 2003) and the reader's own identity (Arya & Maul, 2012).

7.2 Scientific Literacy

The term scientific literacy is used quite broadly, but not always with the same meaning. In general terms, it is understood as the development of three competencies: explaining scientific phenomena, evaluating and designing scientific investigations, and interpreting scientific data and evidence (OECD, 2013), without referring to its fundamental meaning: being able to read and write. Both processes are an integral part of science, as they are the way that research results and theories have been (and still are) shared, whether within the scientific community, the general population, or the school-aged population.

One of the first and more important research groups that studied reading in the science classroom, led by Norris and Phillips (2003), defined literacy or scientific literacy as a conjunction of two different aspects or senses. In a fundamental sense, literacy means the ability to read and write. In the derived one, it means knowledge, learning, and education. Both senses are related, and these authors argue that the ability to read and write is central to achieving scientific literacy, since, in the current state of Western science, a person who is unable to read and write will have serious limitations in acquiring knowledge. Thus, for these authors, being scientifically literate implies not only mastering the big ideas of science but also being able to read and write science.

We also assume that the science class is multimodal, in which the use of different communicative modes (speech, gestures, and visual language) facilitates the overall understanding of the object of study, as each mode contributes specific aspects of meaning (Márquez et al., 2003; Marbá Tallada et al., 2005). Nowadays, no one doubts that visual language as a communication system is displacing written language. Kress (1997) warns that young people are inevitably moving towards a much more economical language, with a more iconic basis, surpassing the adult idea that the most effective way to communicate is through written text.

The visual treatment allows a large amount of information to reach the user without too much effort. In this way, a different lifestyle is being shaped, more sensory, immediate, with a lot of information, presented in a way that the receiver can process it with minimal time and effort. This trend can be easily observed by comparing textbooks – including digital versions – from recent decades, where the incorporation of images, animations, hyperlinks, text format, typography, design, color, etc., contribute to the new treatment of information.

Images are, for various reasons, essential for science. They play an important role in the conceptualization of certain scientific concepts or ideas. In the history of science, we find some examples of fundamental representations, such as cell structure, particle representation, atomic orbitals, and matter cycles. Many scientific entities are inaccessible to everyday perception and require a visual representation to be understood. Also, through images, the order and relationship between different concepts or phenomena can be captured, as in the case of the periodic table, tree diagrams illustrating species taxonomies, food chains, or water cycle diagrams.

In this context, if we want students to understand texts with scientific content, we must help them develop various mental skills or cognitive processes: anticipate what a text will say, contribute their prior scientific knowledge, make hypotheses and verify them, make inferences to understand what is only suggested, construct meaning, etc. Learning to read requires not only developing the mentioned cognitive processes but also acquiring the specific sociocultural knowledge of each discourse, of each specific written communication practice (Cassany, 2006). Likewise, scientific literacy involves not only remembering what texts with scientific content say but also having a critical stance towards them. Reading means understanding, interpreting, analyzing, and criticizing texts. Critical reading has become one of the most impressive tools for living in a society where science and pseudoscience often use the same channels and communication formats, as authors as Osborne et al. (2022) emphasize.

In this situation, students need to develop and apply a series of skills and abilities (Márquez & Prat, 2005), such as:

(a) To be responsible and autonomous for their education, which begins in the compulsory school period and must last a lifetime. The student – gradually – must be able to set learning objectives and evaluate the results. They must be the one who selects the data, restructures it, expands or contrasts it, who ultimately makes personal and discretionary use. They must become their own teacher to the extent that they apply what they have learned in other situations and evaluate it.
(b) To be eager to learn. They must be explorers, who enjoy learning and want to know more. They work to deepen their knowledge of topics of interest. They live and follow the day-to-day advances of science, informing themselves to become responsible and participatory citizens. They seek information to solve questions and formulate new ones, and they should transfer knowledge to new, unforeseen situations.
(c) To be creative, with a sense of discovery, research, to achieve personal results from increasingly comprehensive use of software tools, hardware, and more commonly used peripherals. Considering that a user only uses a small part of the resources offered by the instrument, it is good to give students wings to follow personal paths.
(d) To be critical. The avalanche of information requires more critical readers than ever, who can discern the quality of different information, assess various sources, in this case, the websites or portals that deserve more credibility. A reader who can identify questions, evidence, and arguments and critically evaluate them.
(e) To be part of a community. They must feel like a member of a community (must be able to perform meaningful tasks). Tasks must be challenges, and always authentic and multidisciplinary. Authentic because they must refer to issues of

the family or work world, today or in the future. They must be complex and require a lot of time and effort to solve. They must ask for the collaboration of teachers, family members, and people both inside and outside the school environment.

(f) To be capable of sharing tasks. The classroom must be conceived as a learning community that builds knowledge. A community that should not be closed but should have a very wide environment to contrast points of view and opinions, define objectives, converse, work together.

7.3 Texts Used in Science Classes

As mentioned earlier, today's students can learn science from various types of text beyond the school textbook: press articles, blogs, novels, Twitter, etc. (Fang, 2013). These textual typologies are the ones that will last beyond their school life, so it is essential that science classes work with texts that help connect school science to real life and consider the concerns and interests of students (Oliveras et al., 2013). The use of textbooks continues to be one of the main ways of teaching school science, despite attempts by educational administrations, research in science education, or groups of teachers, to incorporate the multitude of available resources into teaching practice.

Textbooks represent the public discourse accepted by the teaching community, in which the content considered basic for students to be able to explain real-world facts is consensually collected. Despite their great scientific importance, they are not always optimal from an educational point of view. The type of language they use and the way they present science can communicate to readers a vision that increasingly distances itself from their interests, causing a disconnection between personal conceptions and concerns about the world and the knowledge that appears in the books.

In science classes, popular science texts are also used (McClune & Jarman, 2010). This type of material, in principle more engaging, does not always attract students despite using more current communication techniques than in textbooks, especially images and diagrams. Popular science texts deal with current topics and have some social relevance. They usually begin by establishing a connection with the reader, posing or problematizing known situations that they intend to answer, but generally the distance between what the text presents and what the reader understands remains considerable. Reading them also requires learning and guidance from teachers so that the effort of comprehension is not disproportionate to the information they obtain. The goal is for the student, based on their knowledge, to establish bridges that allow them to understand the text and learn from reading.

Another resource that has become widespread in classrooms is the use of the Internet as a basic and regular work tool. Its application has brought about an enormous change in the understanding, management, and updating of information. In Internet documents, the reader has more prominence but also more responsibility because, thanks to the information being structured in networks (not linearly as in written documents), they can select routes according to their intentions and interests. Another feature is that most documents are presented in multimedia formats, with graphics, images, videos, and sound. But the main problem may come from the amount of unselected, unverified information of all kinds found on the web. These aspects shape a reader who knows how to search for information, who has criteria for choosing between different options, is technologically trained, accustomed to interpreting diagrams and images of all kinds, and capable of constructing knowledge from information in any format in which it is presented.

The use of narratives in science classes is also justified by considering the difference between two distinct but complementary modes of thought (Bruner, 1986) through which humans order experience. Bruner calls the first paradigmatic – logical, scientific, and reasoning-based – and the second narrative – sequential, action-oriented, with multiple details, and influenced by feelings and emotions. Specifically, he considers narrative as the way we organize thoughts in our daily lives, that is, the default mode of thinking. Thus, narrative becomes, in part, the way people understand the world they live in, and also serves to communicate this understanding to others (Bruner, 1986). There is an important difference between the two types of thinking: while logical and scientific constructions require verifiability, narrative constructions only require plausibility. Narratives are, then, a version of reality in which their acceptance is governed by convention and a "narrative necessity" rather than empirical verification. It is, therefore, following these arguments that Adúriz-Bravo (2015) considers that in science classes it is necessary to include narrative rationality to rediscover the advantages of objectivity.

Specifically, when we refer to narratives, we do so in the sense of a literary genre, and the concepts of novel, story, narration, tale, and history are used synonymously, understanding that they are representatives of this genre. There are numerous studies that justify the opportunities of using narratives for scientific education. They consider that their use allows making science more meaningful, relevant, and accessible to the public, and favors the understanding and recall of information. The potential of narratives to make science more inclusive for students and to promote a more global understanding of facts is also valued. They can also promote imagination, creativity, and the ability to empathize, as well as learning about the nature of science. Specifically, it is considered that stories can help evolve stereotypical images of scientists. The ability of narratives to promote learning and discussions about ethical aspects, as well as the relationships between experiences and inquiry, is also highlighted. It is also noted that science fiction can serve as an analogical model, in addition to allowing thinking about possible developments and their social repercussions (Pau & Márquez, 2018).

For all these reasons, we understand that incorporating a wide range of documents in the education of students should be a goal of science teaching because it would prepare future readers, emphasizing the idea of forming reading subjects (Da Silva & Almeida, 1998), with an interest in continuing to read and study once compulsory education is completed.

7.4 Characteristics of Scientific Texts

We often wonder why science texts are so difficult for students to understand when, from the expert's point of view, they are easily comprehensible. The role of scientific language, the nature of the information presented, the rhetoric, and the audience of the texts make meaningful reading in science a difficult task for those who are either learning science or are not experts.

7.4.1 The Language of Scientific Texts

Scientific language is the means of communication for exposing, discussing, and debating scientific ideas and has well-defined characteristics: it is precise, rigorous, formal, impersonal. It even has a grammar in which the function of verbs and nouns is different from that of everyday language (Halliday, 1993). Scientific language prefers the use of impersonal forms, unlike everyday language, which prefers personal forms. Impersonal forms are particularly suitable in descriptions of experiments, as they focus attention on what is being done, "the mixture is heated," not on who is doing it, "our research team heated the mixture..." However, the infrequent use of personal forms can have an unintended effect: the disappearance of people as agents or actors in scientific activity.

Scientific language tends to replace processes expressed through verbs with nouns. For example, it replaces water evaporates with the evaporation of water, that is, it nominalizes. The words are the same, what has changed is their grammatical form, evaporate, a process expressed through a verb, is replaced by evaporation, a noun. This view of the world in which processes become nouns and transforms a world in which things happen into a world in which there are things, can be difficult for some students to assume.

The use of these verb tenses and nominalized expressions results in a high degree of abstraction in scientific language. The result, according to Lemke (1997), is "...a strong contrast between the language of human experience and that of science [...]. This leads students and people in general to assume artificially and deceptively that science somehow remains outside the world of human experience, rather than being a specialized part of it.

We can therefore deduce that the language of science often acts more as a barrier than a bridge to facilitate knowledge for most students. Students accustomed to direct, contextualized conversation, which combines linguistic resources with gestures, gazes, tones of voice, and the possibility of reformulating or asking for clarification through dialogue, find themselves in a very different situation when faced with a scientific text. In front of it, each reader only has the baggage of their knowledge (not always coinciding with what the author assumes) and their ability to interpret and make sense of the unknown. It is difficult to imagine meanings for unknown words or to make hypotheses about the content of texts, as inferences can lead to erroneous deductions. It is even more difficult to relate the content of a text to a scientific model if it is not explicitly expressed. Also, in texts, many scientific concepts and ideas are expressed in a "compressed" way through a name or term. Most of these scientific terms are the result of a long process, the need to find a word that defined a set of relationships, an idea, a particular and new way of seeing a phenomenon (Sutton, 1997). For the people who propose them for the first time and for scientists, these words are full of meaning. These same words, so significant for science, lose part of their meaning for non-expert readers. To exemplify the compaction of language, we can look at what the term "microwave" means for a scientist and for a non-expert in science. For the former, it refers to a way of transferring energy with certain characteristics related to wavelength, amplitude... All these references are far removed from the everyday meaning attributed to this term as something made up of many things together. When the scientific term "microwave" appears in a text, all those ideas are implicitly understood. On the other hand, the everyday meaning, which is the starting point for the student, is not considered.

The decoding process can be very complicated for the student if they have no other references than the text they are reading because students develop scientific knowledge throughout their lives. A word, a concept refers to and relates to other meanings and thus acquires consistency, because the meaning of terms is constructed.

7.4.2 The Nature of Information

In the previous section, we have described some of the characteristics of scientific language and the difficulties it entails. With language, meanings are constructed, that is, by relating the different concepts that appear in a text, the reader constructs their own meaning. Following the analogy proposed by Olson (1994), we understand reading as the encounter of three worlds to construct meaning: the world of paper (which refers to the information presented in the text), the world of the reader (their references, knowledge, experiences...) and the world that surrounds us.

In this section, we will describe what the world of paper is like in science texts.

In this world of paper, the information that appears can refer to facts of the world, theoretical models, or scientific facts (facts of the world interpreted according to a theoretical model). In it, the facts and phenomena of the world are expressed according to the author's own interpretation, not as they are in reality and therefore will only reflect those aspects that the author thinks are most important and will not mention those that are not important to them. Although it is understood that the interpretation will follow the lines proposed by the scientific community. Having overcome the aspect of assuming that science texts reflect the author's own interpretation, it is necessary to emphasize how the information is presented.

We propose that the text presents the information in such a way that a non-expert reader in science can discriminate between what is a fact, what is an interpretation (a scientific fact), and what refers to the model that allows interpreting the facts.

From our point of view, it is interesting that the text facilitates the non-expert reader to easily identify which fact is intended to be interpreted. We propose the need for the model to be made explicit in the text so that the reader does not have to infer it, since if the reader can discriminate what the model is, it is easier for them to use it to significantly understand the interpretations that appear in the text. We also think that it is interesting for students to be able to discriminate between facts and scientific facts, not only so that science does not lose its interpretative capacity but also to promote the evolution of their own knowledge models.

In previous research (Marbà Tallada, 2004), we noticed that in the analyzed texts, it was difficult for the non-expert reader to identify which fact was proposed to be interpreted in the text, although most of them dealt with topics close to the reader. For example, one of the analyzed texts (from a textbook) presented the characteristics of living beings (they are made up of cells and perform the functions of nutrition, relationship, and reproduction) without relating this generalization to any specific and known living being for the students (such as, for example, without showing that a dog is a living being). This implies that the reader will have to infer what relationship there is between the world (in the previous example, any living being) and the model (the generalization) and what prior knowledge they should activate to read meaningfully.

When a text does not explicitly present the model, but only uses it to interpret a fact (which is often difficult to discriminate), the author will use entities of the model, abstract constructions that have an interpretative purpose as if they were objects of the world since they are not presented within a knowledge model. This makes it difficult for the non-expert reader in science to discriminate between what is a fact of the world and what is an interpretation. To exemplify this statement, a paradigmatic situation is presented in press articles where reproductive problems of different animal species are related to environmental pollutants because they modify hormonal balance, without emphasizing the scientific model that allows this interpretation. Thus, the non-expert, to make a comprehensive reading, will have to infer the model that allows interpreting this fact (there are species with reproductive problems) is that cells react to certain stimuli, those for which they have receptors, generating a response at the cellular and individual level. If they do not, all the scientific facts proposed by the text will be interpreted as things that really happen in the world, and they probably will not be able to incorporate any new aspect into their own model. Making the world of paper meaningful and understandable for the reader is a task that, as teachers, we must assume, acting as a bridge between both worlds.

7.4.3 Rhetoric and Audience

Scientific texts, like other texts, can be classified according to the relationship they intend to establish with the reader. Thus, univocal texts are those with a transmissive function; what the author writes is what the reader understands, but only one voice is heard, which in this case is that of the expert. Misunderstandings, the dysfunction between the content of the text and what the reader understands, can only be attributed to defects in the communication channel, that is, to the form the author has given to the text. These are texts to study in the traditional sense, which is synonymous with memorizing, proposing a complete science, with unquestionable truths, without gaps, and therefore, should generate unconditional loyalty from the reader. This function, at some moments and specifically with pedagogical models based on the transmission of knowledge, has been understood as the very essence of the text.

At the opposite pole are the dialogic texts which, as their name indicates, have the intention of communication between two or more people or even with oneself, through discussion, reflection, contrast, analysis. Their function, contrary to univocal texts, is to generate new meanings. It is in this sense that texts are understood as "devices for thinking" and the value attributed to them is to provoke, favor divergences of meaning between incoming and outgoing messages (input and output).

To a greater or lesser extent, all texts should be – or are – dialogic, since it is impossible for a reader, once a reading is finished, to obtain, for various reasons, the same information that the author intended to generate. Reading is understanding by putting into play knowledge and inferential mechanisms, as we said in the previous section, it is making three different worlds interact. Likewise, scientific texts have a certain way of presenting the world to the reader. For this reason, we can speak of the rhetoric of texts since they have a clear persuasive intention. Four narratives or ways of presenting the world have been identified: (i) the apocadiptic show that the "world is like this"; (ii) the magisterial refers to an idealized or grouped phenomenon in a certain way (which is convenient for the author); (iii) the rhetorical doubt where a doubt is raised or a problem is presented that will later be resolved in the same text and iv) the real doubt where the author presents different interpretations of the same theme (Izquierdo, 2005). Behind each of these narratives is a specific vision of science, and in Izquierdo's (2005) research, it is found that texts are heterogeneous, that is, they present different narratives, although there is always one that predominates, and this can complicate meaningful understanding for non-experts.

7.5 Reading in Science Classes

Teaching reading is a task that historically science teachers have left in the hands of language teachers, as it is related to a good mastery of the reading process. But as Sanmartí and Izquierdo (2003) say, from learning the reading process, each discipline must teach how to read its own texts. Reading is a complex process that requires the use of cognitive and metacognitive functions. The view of reading as a passive activity, completely directed by the text and with a process where meaning was already constructed has been overcome. And the new vision is that reading is an active process of constructing meaning from the text. Acquiring good reading competence contributes to scientific literacy, considering that being scientifically literate implies not only understanding the great ideas of science but also being able to speak, read, write, and problematize arguing based on these ideas.

In the European educational framework, reading is proposed as “understanding, using, and reflecting on texts to achieve one’s own goals, develop knowledge and one’s own potential, and participate in society” (OECD, 2001). This goal is ambitious and there is no doubt that achieving it will require working together in different subjects. From science education, we believe that the autonomous and meaningful reading of all types of scientific dissemination texts should be learned in science classes to allow students to modify and acquire knowledge throughout their lives (Márquez & Prat, 2005; Martins, 2004). Meaningful reading is one where the reader is aware that reading is making the real world, their knowledge, and the paper world (an analogy proposed by Olson (1994) referring to the world presented in the text) interact to evolve their own knowledge models.

Beyond promoting this meaningful reading so that students evolve their own knowledge models, it is also necessary to make them aware of how they regulate this entire process, that is, what information they incorporate and what they do not, and what depends on them doing so. In these last decades where more and more information is shared without necessarily being validated by the scientific community, it is increasingly important for students to develop epistemic cognition. Thus, due to the impact of science on everyday life and the desire to have a critical and informed citizenship, it is necessary to promote the epistemic cognition of students, assuming that each person has beliefs, meanings, and values about knowledge that influence what is learned (Barzilai & Chinn, 2018). To do this, all types of textual material must be provided in the classroom, including press releases that use scientific arguments, but students should also be encouraged to contribute texts themselves.

When we, as readers, face a text, we can take different positions (Phillips & Norris, 1999): a deferential position (where the reader will allow the information in the text to override their own models without negotiation), a dominant position (in which the reader will impose their own model to override the information in the text, making a consistent and complete interpretation impossible), or a critical position (in which the reader will carry out a negotiation process between the text and their own knowledge to construct their own interpretation, thus promoting epistemic cognition). For this reason, we advocate promoting critical reading among our students because it is the only one of the three that allows for the meaningful incorporation of text information into our own scientific model. Another aspect to consider is the different levels of reading that can be done on the same text: literal, inferential, evaluative, and creative (Wilson & Chalmers, 1988). The characteristics of these four levels of reading are the following:

- Literal reading: Enables understanding of the text. The answer to this type of question is found directly in the text, and therefore it is only necessary to search for it. These are questions that challenge the student’s memory more than their understanding. For example, ask: What does the text say?

- Inferential reading: Enables the use of all the conceptual information that is taken for granted. The reader must be able to clearly formulate ideas that do not appear in the text but are implicit. For example, ask: What things does the text not say but we need to know to understand it?
- Evaluative reading: Enables assessing the usefulness of the information. For example, ask: What does it say that I didn't know? Do I agree text information? It is trustable?
- Creative reading: Enables expanding the field of reading, deducing, relating, applying. For example, ask: What is the purpose of this text? Are these ideas useful for explaining other phenomena?

From this perspective, it will be necessary to propose activities that favor the student's competence in all four levels, as achieving creative reading will enhance the enjoyment of reading and promote a critical stance, and therefore, the development of epistemic cognition.

Currently, in classrooms, the textbook has given way to other resources, although it is still a basic material in many centers. Thus, teaching and learning situations are much more complex, varied, and dynamic and have more resources than just reading: scientific knowledge is also built when talking, discussing science in the classroom, when working, observing, experimenting in the laboratory, when sharing tasks, when searching the Internet, when thinking, when students write and the teacher reviews, when listening. The way to access knowledge from certain linguistic and cognitive skills is not a compartmentalized process, but the boundaries between them blur, so learning a concept requires the conjunction of all of them: people think, talk, read, discuss, write, experiment on a concept, but it is the whole that facilitates access to knowledge.

Reading, like any complex activity, requires a self-regulation to successfully complete it. Therefore, to promote students' construction of their own knowledge, it is necessary to propose activities before, during, and after reading (Márquez & Prat, 2005).

7.5.1 *Before Reading*

It is necessary to situate the reading in the context of the sequence and clearly communicate the purpose of it, what we are looking for, what interests us. It is also advisable to activate the base knowledge that will be necessary to use. Together with the students, a first approach to the texts can be made by visually exploring the titles and subtitles, graphic elements, terms used, etc. From here, try to make predictions about the content of the text. All these activities are aimed at the reader making a first representation of the content of the text, as this aspect is essential to effectively incorporate the new information provided by the reading.

As mentioned earlier, in science class, not only are written texts with educational purposes used. When materials aimed at other audiences (press articles, popular science books...) are incorporated, the teacher must be aware of the need to contextualize this document to adapt it to the school audience.

7.5.2 During Reading

While reading, it is advisable to carry out regulation tasks simultaneously to detect problems, find possible causes, and think of possible ways to solve them. Some of the strategies proposed are:

- Interrupting reading at certain points to ask literal and inferential questions.
- Formulate the ideas that appear in the text using different words than those used in the text itself.
- Construct a scheme while reading, which captures the organization of the text and a summary.

7.5.3 After Reading

Upon finishing reading, it is interesting to reflect on the contributions of the reading and the assessment and interest of these, that is, to draw conclusions and evaluate them. Critically evaluating the text that has been read, both from the point of view of the content and the way it has been presented, helps to make the reader aware of their process of decoding and reconstructing the information.

7.6 Analysis of Reading Situations in Science Classes

We dedicate the final part of the chapter to the performance of teachers, to the bridges they have to build to connect all classroom activities, especially those related to reading, with the aim of each student building knowledge according to their possibilities. To exemplify the meaning of building bridges in reading, we present six activities from Middle School Experimental Science class to show six different aspects: (1) Organization of the reading process, (2) Promoted questions; (3) Meta-reflection on the implications of reading; (4) Nature of textual information, (5) Reading and searching information on the Internet, and (6) Critical reading.

1. Organization of the reading process

   Cooperative groups of four students are organized. Each member of the group reads the entire text individually, but each one is responsible for a part of the reading process: finding the main idea, questions raised by the text, proposed answers, and considerations that go beyond the text, for example, suggesting how it could continue. Later, each student shares their work with their classmates. This strategy can be applied especially in the reading of journalistic interviews and articles that include information with different content (for example, about a character and the content of their work) and/or graphic typology (subtexts separated from the overall text, graphics with illustrations and data).

Fragment 1

At the end of the activity, the teacher asks the students to assess this way of organizing the reading of a text.

S1. I tried to do my part well because it wasn't very long and it was important for the group.

S2. I liked it because the work is more evenly distributed.

S3. I find it hard to understand why the conclusions I reached were different from those of my classmates.

Comment

The teacher has used a resource to highlight the diversity of processes that take place while reading.

The students actively participated in this activity. It is considered that some of the reasons for the potential of this type of activity are: (i.) The teacher, when distributing the reading assignments, considers the students' reading skills. (ii.) Students are given a different assignment than usual, and each one must do a part of the work. It is a joint effort, and the result depends on the work of each group member. (iii.) Regulation among the students themselves, as they are the ones who assess their classmates' work.

Also, the interpretation problems that arise during the activity allow for a deeper understanding that comprehending a text means formulating a prior hypothesis, about the central idea being presented. This hypothesis is constructed based on prior knowledge, among which are prejudices, attitudes, etc.

2. Promoted questions

   The most general strategy is to promote the identification of the main idea of the text. Some of the possible instructions are: write the main idea, give a title to the text, or write a sentence that summarizes the content. In some cases, students are asked to write a summary of the text, in which they must refer to the main idea, the argumentation, and the conclusions.

Fragment 2

The teacher provides them with a text, and they must find the main idea. Among the whole group, they have found many main ideas, quite different from each other. This dialogue arises.

T. Why do you think so many different main ideas have come out of the text?

S1. Because we interpret it differently, because we have different knowledge, different models, different stories.

A2. Because we were not clear about the purpose of the reading.

Comment

The interventions of the two students are in line with reality. Generally, each student interprets the main idea in their own way: the title, the first sentence of the text, a *previous idea, the idea they have understood without difficulty, their intentions... Usually, when reading a text, one seeks to reaffirm what is already known, and it is difficult to challenge previous ideas before reading.*

These are intuitions that, if confirmed, would assign a decisive role to the teacher's role, as a bridge to facilitate understanding.

3. Metareflection on the implications of reading

   Another strategy that we consider interesting is the promotion of metareflection on the reading process itself:

Fragment 3

The teacher encourages a group of 1st-year ESO students to explain how they read. We reproduce a fragment of the dialogue:

P. How do you read?

A1. The first thing I read are the bold words and other highlighted words or phrases because I know that's the most important.

A2. I only read the captions and the bold or highlighted words in some way.

A3. If I don't understand, I ask. And if not, I don't do anything. I don't care because we will explain it later.

A4. I make diagrams to understand it, except in math because it's not possible for me.

A5. I read the first lines and, if they agree with the title, I already know what it's about, and if they continue to agree a little more, I don't finish reading it.

A6. I read quickly or slowly depending on the instructions you give us to read: to explain it later, in case we must make a definition, or if we just must read it to discuss it later.

Comment

Each student has their strategies. Knowing the students' reading strategies is useful for the same boy or girl who makes them explicit, for others who learn new ones and compare them with their own, and for the teacher who can interpret the origin of some errors or habitual attitudes. In these student interventions, there are attitudes of little control of comprehension, mechanical reading, minimal effort, which contrast with those who demonstrate the ability to implement expert strategies.

Help from the teacher can improve individual and collective skills.

4. The nature of textual information

   The activity proposed here is for students to individually underline the information that refers to facts, scientific facts, and models in a given text. After individual work, the classification criteria applied and the difficulties in applying them are discussed at the class level.

Fragment 4

P. Let's see, how have you classified the following sentence: "the captain had forgotten that his weight is really six times less than on Earth..."?

A1. I think it's a fact because it's really what happens... Anyone could say it, maybe they wouldn't know if it's exactly six or five times...

A2. I think it's already a scientific fact because someone who doesn't know science would say the same as the captain: that he jumps more! It has nothing to do with weight.

A3. Yes, because to relate jumping more to weight, you have to know that weight is related to the force of gravity, so Tintin uses science to interpret the captain's jump.

Comment

The teacher's goal is for students to find strategies to discriminate between the three previously discussed aspects (fact, scientific fact, and model) and discuss them among themselves until they reach a consensus. Activities of this type aim to promote the view of science as a specific way of interpreting the world and break the view of science as absolute truth.

5. Reading and searching information on the Internet

   Students are asked to work in cooperative groups to search for information on the web. They are given a form where they must write down the search criteria, keywords, what they expect to find, the type of information they find, the agreement between what they expected and what they found, and the reasons for choosing a specific page or server. In this case, each group was asked to choose an animal and search for evidence that it is a living being. Each member had to search for evidence on a specific aspect of the living being model previously worked on in class.

Fragment 5

The teacher observes a group of students as they search for information on the Internet and what they write down on the form.

P. What animal have you chosen? A1. The cat, because I already have one...

P. So, you would be able to justify why cats are living beings. A2. Yes, of course, and what we are looking for is proof of what we think, right?

P. What are you looking for evidence on, then?

A1. Well, I'm looking for information on the reproduction function, and I have as proof the description of the sexual reproduction process of cats.

A4. But is a description of the process proof?

P. That's what you must discuss: what information and what type can you use to prove that it is a living being. And we are going to call that evidence.

A1. So, do we have to look for evidence that it performs the three vital functions and that it is made up of cells?

A2. Yes, but the websites we find only describe felines or cats in particular, or have drawings. Is that valid as proof? And do we have to read all the information?

A3. Also, if we put the word cat in the search engine, thousands of entries come up and we don't know very well how to narrow it down further.

P. I think you should first think about the search criteria, or the keywords or which portals you would be more interested in working with...

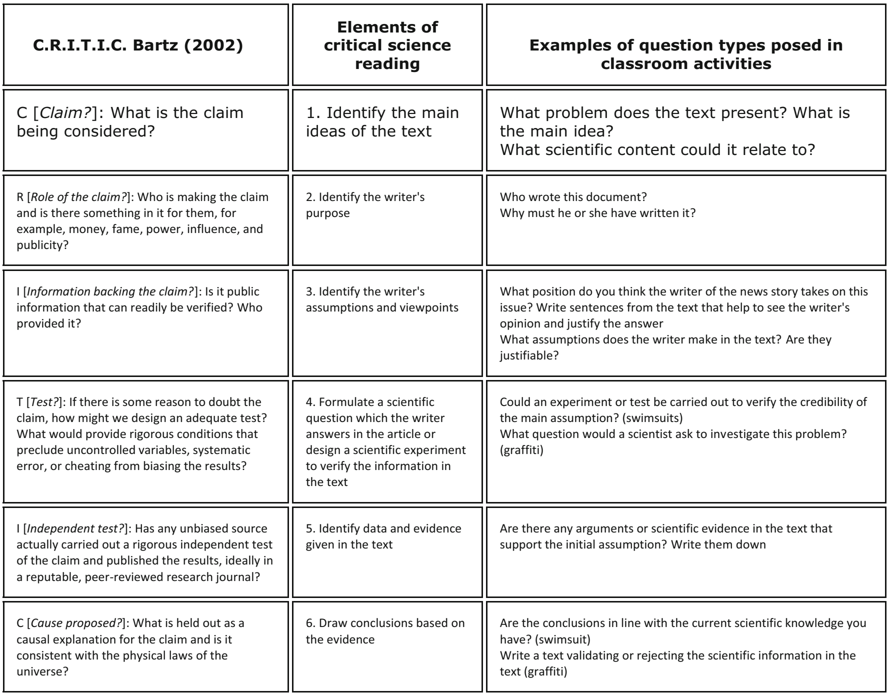
Comment

The students do not have good strategies for searching for information on the Internet. They also do not have the habit of first thinking about what they expect *to find and, therefore, do not decide on useful search criteria, let alone have the habit of contrasting information, as they are used to believing what the teachers or textbooks say. You could start by searching the Internet on pages provided by the teacher, justifying that they are reliable and suitable for the students' level. The issue of keywords, advanced search options, Boolean operators... should also be worked on, as discussing these aspects in depth is actually discussing the criteria. Another aspect to consider is the type of information that is requested to be searched for. In this sense, it is important to ask productive questions, in which the students have to build knowledge rather than simply reproduce (cut and paste) the information they find on the web.*

6. Critical reading

   The objective of this activity is for students to recognize that texts are a cultural instrument contextualized in a specific time and that authors have an ideology, an identity, and an intention that is reflected in the text.

To promote this critical reading, an experience is presented where a press advertisement for an anti-cellulite cream that used scientific arguments was analyzed, using the activity proposal by Bartz (2002) and modified by Oliveras et al. (2013). This author proposes a series of items (Fig. 7.1), ordered to form the acronym CRITIC, in the form of questions to guide the students' reading:



C.R.I.T.I.C. Bartz (2002)	**Elements of critical science reading**	**Examples of question types posed in classroom activities**
C [*Claim?*]: What is the claim being considered?	1. Identify the main ideas of the text	What problem does the text present? What is the main idea? What scientific content could it relate to?
R [*Role of the claim?*]: Who is making the claim and is there something in it for them, for example, money, fame, power, influence, and publicity?	2. Identify the writer's purpose	Who wrote this document? Why must he or she have written it?
I [*Information backing the claim?*]: Is it public information that can readily be verified? Who provided it?	3. Identify the writer's assumptions and viewpoints	What position do you think the writer of the news story takes on this issue? Write sentences from the text that help to see the writer's opinion and justify the answer What assumptions does the writer make in the text? Are they justifiable?
T [*Test?*]: If there is some reason to doubt the claim, how might we design an adequate test? What would provide rigorous conditions that preclude uncontrolled variables, systematic error, or cheating from biasing the results?	4. Formulate a scientific question which the writer answers in the article or design a scientific experiment to verify the information in the text	Could an experiment or test be carried out to verify the credibility of the main assumption? (swimsuits) What question would a scientist ask to investigate this problem? (graffiti)
I [*Independent test?*]: Has any unbiased source actually carried out a rigorous independent test of the claim and published the results, ideally in a reputable, peer-reviewed research journal?	5. Identify data and evidence given in the text	Are there any arguments or scientific evidence in the text that support the initial assumption? Write them down
C [*Cause proposed?*]: What is held out as a causal explanation for the claim and is it consistent with the physical laws of the universe?	6. Draw conclusions based on the evidence	Are the conclusions in line with the current scientific knowledge you have? (swimsuit) Write a text validating or rejecting the scientific information in the text (graffiti)

Fig. 7.1 Elements of science critical reading

Fragment

It is proposed that in a cooperative group of five people, they analyze the following advertisement:

Lose an inch? Up to a 1 inch reduction around the thighs to be exact. This is the result from using Clarins Total Body Lift twice-daily after only one month*. And along with these amazing results, Total Body Lift also visibly reduces stubborn cellulite and immediately smoothes, moisturizes and enhances the skin's beauty. Your hips appear more streamlined, your legs

Each person must solve all the demands (except the last one, which is resolved collectively in the workgroup). After an initial moment of individual reflection, all the people who have the same task meet to reach a consensus and be able to communicate it to their original group and thus resolve the last demand, which is the Conclusion.

In general, students make partial readings (they do not read the entire text or do not read the images). The fact that some tasks involve two questions means that some answer only one, so the questions should be rewritten. Most of the groups (all except one) have recognized the commercial purpose, but on the other hand, no group has identified that the prevailing Western society's aesthetic standards promote success and happiness to a specific body image. Most of the groups assume that if the advertisement talks about an experimental test, it is because it has been done and is scientifically valid.

Comment

Students do not have developed epistemic cognition if it has not been promoted previously. Therefore, activities that promote critical reading of the information *presented should be incorporated, discussing concepts such as authorship, truthfulness, or the validity of the information. It is also important to discuss what things we believe and why, as it has been proven that positioning on socio or pseudoscientific issues responds more to the ideological and personal principles with which each person identifies than simply a series of factual premises (*Nielsen, 2012*). Students should be aware of what things they believe because the scientific community supports them and are the result of habit, or because they are of their own ideology and have no scientific validity.*

7.7 Final Thoughts

Nowadays, science curriculums aim to provide a series of skills for the student to continue learning throughout life; to form people interested and capable of knowing and understanding science, with an interest in seeking information and the ability to participate in society's debates.

There is no doubt that one of the basic skills that students must acquire in science class is reading comprehension of science texts. Reading is a fundamental part of the process of acquiring scientific knowledge. This idea of forming citizens committed to their time and interested in lifelong learning leads us to incorporate all kinds of textual typologies in the classroom. In this way, and using appropriate activities and methodologies, we will promote the internalization of the necessary strategies to be able to discriminate information, decode it, and reconstruct it according to each person's identity and being aware of how each step has been taken. Understanding a text, therefore, does not only imply accessing the information that the author transmits to us, but also elaborating it personally, using knowledge acquired in other situations and circumstances. This is why it is essential that students can reflect on the reading process (how they choose a text, what information they read? And of what they read, what do they incorporate?, what position do they have in front of the text?, is it always the same? etc.).

Now, we currently have evidences that open paths for reflection and also guide us in practice: teachers from no linguistic areas should also assume students' linguistic competence development, but training is needed to be capable of this.

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Chapter 8
Reflective Dialogic Journals in the Pre-service Biology Teacher Education

María Inés Copello

"The school curriculum, which has always been characterized by authoritarian relationships, the apparent privilege of reason, and the function of transmitting knowledge, has recently lost all these characteristics, being limited to a space/time in which subjects isolate themselves for part of their day, without knowing "what they are going to do" (sometimes that doing is limited to working with the textbook) and "why" they are there (...). We are faced with the challenge of transforming ourselves and transforming the curriculum into one of the processes of constructing social subjects who, through reflexivity, deliberate activity, and collective imagination, can be aware that both they and society are constituted by the people who compose it and that, for this reason, it presents the possibility of being (re)created as an autonomous society, therefore, permanently constituent". Teresinha Fróes Burnham

8.1 Introduction to this New Version of the Chapter

In recent times, I have been involved in a thousand activities. This led me to a considerable delay in revisiting this text. I must admit that only the insistence of Mario, the great friend and coordinator of this publication, determined that I have done so. I want to thank him very much for his efforts in urging me to do this. Again, as in that first edition, it has meant pleasure and also enrichment. Reconsidering a text that discusses aspects of teaching work from 2003, 16 years ago, and verifying its relevance in this 2021. At that time, Brazil, Universidade Federal do Rio Grande, training of biology teachers, today Uruguay, Universidad de la República, training

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for university teaching in formal and non-formal education. But the reflective dialogic diaries are still present, as are several other foundations discussed in this chapter. New dialogues with other authors have deepened and enriched the conceptions in which we work, but the essence of a process that began in 1993 and crystallized in the 1997 doctorate remains present.

With the project somewhat closed, having presented it to our guiding teachers and having made some modifications, we could perceive that we had ambitious objectives, which was not unfeasible and possible. This aspect motivates our task even more and confronts us with a new challenge as students and teachers in construction, and from there we position ourselves in this process of being teachers, in this practice as a challenge: on the one hand, successfully achieving, with our task, the objectives proposed in the project; on the other hand, our own construction of being a teacher (excerpt from Diary published in Copello, 2010, p. 152).

As the time approached, I felt more and more like a Roman legionary who only has his shield and spear to face a whole horde of barbarians, I don't want to be politically incorrect, let alone be mean to the kids, but the picture they had painted for us was quite gloomy... The kids finally arrived, entered orderly and greeted each of us with a kiss on the cheek, which made me see that the situation was not as difficult as they painted it (excerpt from Diary published in Copello, 2010, p. 149).

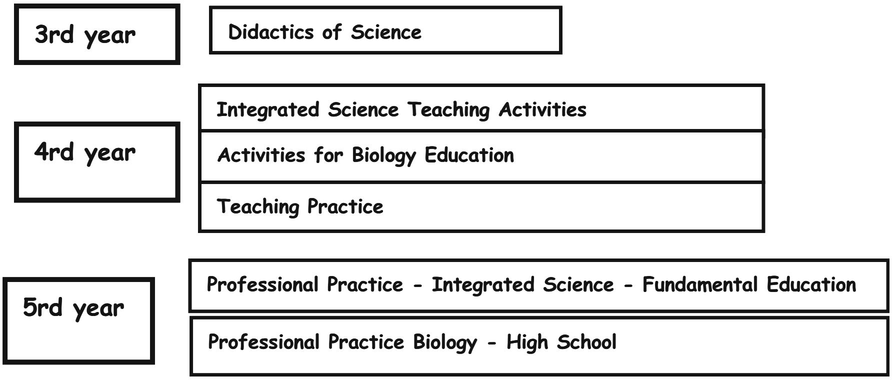
8.2 Original Introduction

This chapter aims to share, with teacher training professors and student teachers, especially in the area of natural sciences, some considerations regarding a work that aims to think, analyze, evaluate, and apply a teacher training model. The process is based on the commitment to the formation of a creative, autonomous, and reflective professional, capable of sharing their activities within a Learning Community driven by theoretical foundations that are worked on and assumed as shared.

It begins with a section that outlines the context in which the process was worked on and central ideas regarding its characteristics. In a second section, some central ideas of the theoretical foundation of the model are shared. Next, one of the activities that are part of the work of an academic year in which students are carrying out professional practice is analyzed: it focuses on analyzing the use of reflective dialogic diaries. As explained later, the professional practice work is carried out through a set of activities that interrelate and support each other (Table 8.3). In turn, professional practice is the culmination of the work carried out in six disciplines over 3 years of training (Table 8.1).

Within the extension of this text, it was impossible to discuss the different professional practice activities, let alone those involving the set of six disciplines. We chose the reflective dialogic diaries as a cutout of the work done, considering them one of the interesting aspects to be analyzed and that receive influences and contributions from other activities; they alone would surely not have the same characteristics. The text ends with an invitation to its recipients to create and share

Table 8.1 Sequence of disciplines involved in the training model. (Author's elaboration)



3rd year	Didactics of Science
4rd year	Integrated Science Teaching Activities Activities for Biology Education Teaching Practice
5rd year	Professional Practice - Integrated Science - Fundamental Education Professional Practice Biology - High School

proposals that result in alternatives to vary the activities, perfect aspects already included, and expand the context of their application.

We want to express the pleasure that the elaboration of the text gave us, which allows us to share a much-loved work. Especially, it was gratifying for us to be able to analyze and bring to the knowledge of an expanded community the writings of our students. We are proud and feel that it was a privilege to interact with groups of students that we saw evolve in their conceptions, beliefs, practices, feelings, and whom we learned to value and love deeply.

8.3 Outlining the Context

In the nineties of the last century, during 4 years related to the doctoral thesis, we focused our work and reflection on thinking about new paths for the training of natural sciences and biology teachers. This issue occupied and challenged us since the mid-70 s, when we became involved in the training of these teachers at the Federal University of Rio Grande. The doctoral research led us to experiment, analyze, and propose a model of continuous training for biology teachers (Copello, 1998a; Copello & Sanmartí, 1998, 2001a).

Upon returning to activities in Rio Grande, and teaching in the pedagogical disciplines of the scientific teacher training programs (Biology, Physics, Chemistry, and Integrated Sciences), we decided to apply this process in the initial training of these teachers. The process is linked to a set of disciplines that begin in the third year and continue until the fifth year, the last, of the course (Table 8.1).

Concurrently, we chose to continue the research regarding the outlined model (Copello & Sanmartí, 2001b). In this sense, we have data collected over 6 years of

Table 8.2 Activities of the training model in the Science Didactics discipline (Author's elaboration)

Activities	Characterisation
"Career expectations: Why am I on the teacher training course?"	Explaining and questioning the motivation that leads students to study for a teaching degree (students study for a teaching degree and a bachelor's degree at the same time, and the majority of them have the attitude of prioritising the bachelor's degree and devaluing the teaching degree). This questioning is aimed at counteracting this devaluation.
"Clippings from my life story".	Experiences as a student, which highlight the conceptions of the profession as well as the positive and negative perceptions in relation to learning science.
"I know the reality".	Observation and analysis of real classrooms in community schools. Emphasis is placed on a contextual analysis that raises judgements and arguments without the attitude of "censorious critics" of the person of each teacher and pupil observed.
"Playing at teaching"	Initial teaching experiences. It is based on intuitive conceptions and it is "allowed" to make mistakes, to become aware, to start again. The concept of "play" does not devalue the situation, but points out the spontaneous, motivating and stimulating character of some initial reflections.
"I build a frame of reference"	Reading, analysis, discussion and elaboration of texts, based on updated bibliography of Didactics of Science.
"I know innovative experiences"	Observation, analysis and discussion of classrooms (on video) of teachers working on innovative experiences (linked to the process of lifelong learning).

work. In a previous article (Copello, 2002), we discussed the training process in the discipline that initiates the process: didactics of science. Table 8.2 aims to explain, albeit synthetically, the characteristics of this initial process. In this way, although only partially, we hope that the reader can establish some ideas concerning the integral process.

In the work, we share reflections and analysis that emerged from data collected in 2003 in the fifth-year disciplines, Professional Practice in Integrated Sciences and Biology. Between the years 1998 and 2002, we individually coordinated the process and applied it in the third and fourth years (four disciplines). In 2003, Paula Regina Costa Ribeiro returns from her doctoral course, with a Ph.D. in Science Teaching. Then, between both of us, we share the work, and for the first time, it is possible to work on the integral process with the group that started the discipline Didactics in 2001. The work in the professional practice disciplines is based on the foundations established in the general model and is materialized in a series of activities (Table 8.3), all of them complementing each other in the pursuit of the main objective of initial teacher training.

Table 8.3 Activities of the training model in the professional practice disciplines. (Author's elaboration)

Type of activity	Characterisation
"Orientation meetings"	Meeting with one of the counsellors, individually or in a small group of students who are planning similar activities.
"Reflective Dialogic Diaries".	The "diary" is written after the end of each class day and sent to the counsellors via e-mail. It is answered, establishing an exchange of opinions. Sometimes it is socialized with the whole group, also virtually.
"Accompaniment and guidance visit in the classroom".	At least twice each student is accompanied by a counsellor during the work in the classroom. The counsellor takes notes of the observations and, when leaving the classroom, shares and discusses them with the learner. In some situations, she acts as an observer-participant interacting with the trainee and the pupils..
"Reflection meetings and group dialogic communication".	Meetings of the whole group of practitioners and counsellors. Space is given for everyone to comment on the development of their work, successes, difficulties, situations experienced in the context. Opinions are exchanged and consensus solutions are agreed upon.
"Article"	The final report, classic in the discipline of professional practice, is replaced by the preparation of an article, along the lines of those prepared for scientific congresses in the field. The subject of the article is freely chosen by each student and deals with an aspect of the experience that is relevant to him/her.
"Consensual evaluation and grading meeting"	Individual meeting of the counsellors with each practitioner in which he/she self-analyses and self-evaluates, the counsellors carry out an analysis in the same sense and a consensual grading of the work is reached.

Thus, we now have data from the comprehensive application, and it is our interest to investigate the entire process applied to the initial training of science teachers. We intend to carry out an analysis and evaluation of it, correlating the activities and their mutual influence throughout a three-year process and six mutually supportive disciplines. However, this analysis is beyond the scope of this chapter. Seeking a manageable focus within the available space, we decided to analyze the contribution of reflective dialogic journals in the initial teacher training process. These journals, which constitute one of the activities that make up the teaching practice work, have seemed to us a very significant, relevant, and innovative activity, as well as an unprecedentedly used instrument. Hence our interest in sharing reflections related to them. In this way, we aim to give and receive new contributions in an area of evident interest: the structuring of new paths that collaborate in the training of teachers prepared to face the challenges of the necessary school in today's society.

8.4 Foundations of the Process

We start from the conception that training actions, both in initial and ongoing training, should lead teachers to achieve a theoretical foundation for their actions, consistent with the new knowledge being developed about the teaching and learning process of science, which already constitutes a paradigmatic area of knowledge. Along with this, linking this knowledge with procedures for action in practice. As we understand that changes in the value system and attitudes are also necessary, it is essential that the entire training process be linked to critical reflection both in relation to the current way of teaching natural sciences and the new paths proposed. And all this, taking into account the consideration of the socio-cultural context of action and the emotional world of the teacher. This process should promote both the ability to act in the specific working conditions (Domingos, 1989) and the development of self-esteem and obtaining satisfaction in the exercise of the profession (Copello, 1998a; Copello & Sanmartí, 1998, 2001a).

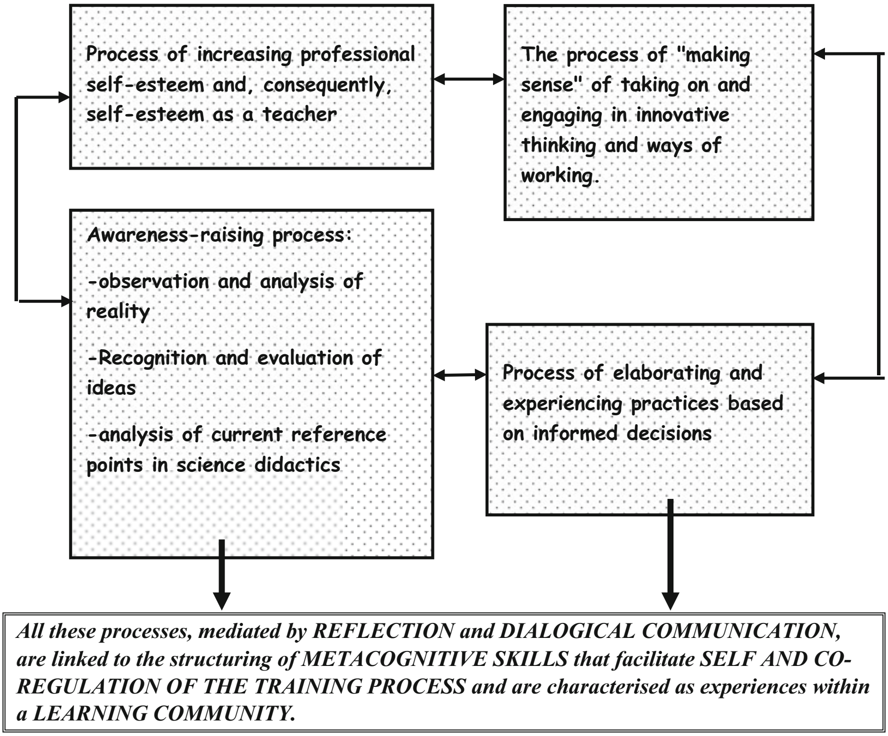
It is on the basis of these considerations that we set out to think about a didactical training process for natural science teachers (Table 8.4) that, starting from their conceptions and practices, promotes awareness and decision-making that, in turn, generate improvements in the teaching and learning process in the classroom. This implies that the variables of the training context and the context of each teacher are important starting points.

In search of outlining this process, we decided to "dialogue" with authors who propose the revision of practice based on a theoretical positioning: knowledgeable action (Porlán & Rivero, 1998) or educational praxis (Grundy, 1991). We also included the contribution of authors who argue that the teacher training process should be of a metacognitive nature (White & Mitchell, 1994; Baird et al., 1991), that is, that in becoming aware of the reasons, metacognitive skills are developed that, in turn, allow for conceptual, procedural, and attitudinal self-regulation, with respect to the teaching and learning process of science in particular, and more generally, to their performance as an educator.

It has been intended to structure the training of natural science teachers in such a way that it enables each teacher, working within their conceptions and practices, to become aware of them and make decisions that impact a reflective-critical teaching practice. The aim is to find paths that can help new teachers develop skills and attitudes that allow them to join the group of active teachers who propose the importance of maintaining the school in an era that questions it (Simons & Masschelein, 2014; Larrosa, 2017). But, at the same time, that defense is allied with new ways of understanding and working in it. This process is complex, affecting theoretical-practical knowledge and values, so it necessarily has to be worked from a holistic and systemic perspective (Copello & Sanmartí, 2001a).

This process has as its integrating axis the mediation of reflection and dialogic communication within a learning community. The concept of "dialogic" is based, following Vygotsky and Bakhtin (Wertsch, 1988, 1993), on social interaction as a privileged strategy to promote and facilitate the construction of knowledge.

Table 8.4 Process of didactic training of natural science teachers. (Author's elaboration)



All these processes, mediated by REFLECTION and DIALOGICAL COMMUNICATION, are linked to the structuring of METACOGNITIVE SKILLS that facilitate SELF AND CO-REGULATION OF THE TRAINING PROCESS and are characterised as experiences within a LEARNING COMMUNITY.

Incorporating this idea, we understand that the quality of work, aimed at providing spaces for reflection and communication, will be related to the quality of the training process of each teacher. The activities have in common the problematization and elaboration of arguments (reflective character) and the construction and exchange of points of view, oral and written (communicative character) (Galiazzi, 2000; Moraes, 2000). The process is always experienced in the form of dialogue: with colleagues, with the mediating teachers of the process, with the authors of texts, with themselves (self-reflection is understood as dialogic). We believe that linking reflection and communication enriches and enhances the dialogic nature of the process. Today, in 2019, in the continuity of these ideas, although in other scenarios, face-to-face communication or via emails is expanded and enriched with the use of virtual platforms that streamline dialogues and the organized registration of them.

This experience of reflective-communicative situations occurs within a group that interacts by supporting each other. This mutual aid character was worked on from the beginning of the structuring of the process based on the concept of empowerment (Baird et al., 1991) - translated as "companionship" (Copello, 1998a). Lately, we have incorporated into this concept the contributions on learning communities, which we understand expand and enrich the concept (Orellana, 2002; Périssé, 2003). Orellana (2002), supported by Vygotskian and Freirean framewoks, works on the theory of learning communities with the orientation that dialogic interactions in educational relationships produce stimulating and meaningful conditions, common values that generate a know-how, know-how-to-do, and know-how-to-live-together, in solidarity and responsibly. This author understands the concept of a learning community closely related to the notion of dialogic relationship and links dialogue to three elements in dialectically linked and inseparable dimensions: reflection, practice, and problematization. She affirms that this triple dimensionality leads to the integration of knowledge and interdisciplinarity:

From a hermeneutic point of view, it is about ensuring the intersubjectivity of the understanding of communication, the key to dialogue, without losing sight of the cultural context in which it is generated. [...] In the context of a learning community, dialogue appears [...] as a creative act. [...] This creative act is stimulated by the process of integrating knowledge of various types and linked to the abandonment of certainty. This is perceived as a trigger for creativity and thought and as the driving force in the search for solutions to problems. (Orellana, 2002, p. 223).

The continuity of the study of these foundations has led us to enrich Orellana's contributions in dialogue with the proposal of Communities of Practice (Wenger, 2001) and with the conceptions of Situated Learning and Legitimate Peripheral Participation (Lave & Wenger, 1991). Space does not allow us to develop them, but we understand it is important to point out these contributions.

We see, therefore, that by incorporating these concepts, we understand the work carried out during 2003, in the two consecutive disciplines - professional practice in sciences and biology - as a training process mediated by reflection and dialogic communication, within a learning community, an organized group that constituted a space for the exchange of ideas, discussions, cooperation, collaborative research, confrontation of points of view, and negotiations (Table 8.5). Périssé (2003) states that the transformation of a typical twentieth-century school environment into a twenty-first-century learning community must involve the way educators perceive themselves, how they perceive students, and how they organize and conduct the teaching and learning process.

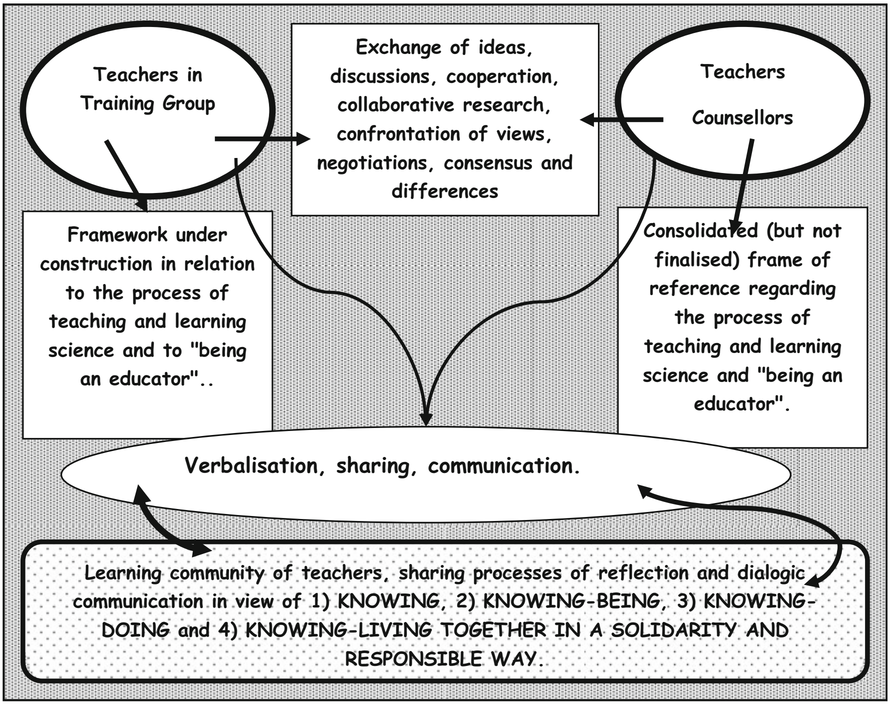
8.5 Reflective Dialogic Diaries

Hello, teacher!

I am sending in attachment the story of my first week of classes, I tried to remember everything in detail to know if my performance was good or not. I made some small modifications [to the structure discussed in the orientation meetings] in the development of the classes, I hope everything went well. I await a response to my e-mail. Don't forget that on the 15th we have to discuss the next class.

A hug from your fifth-year biology student, Cristina.

Table 8.5 Training process mediated by reflection and dialogic communication within a Learning Community. (Author's elaboration)



8.5.1 Group of Teachers in Training

Framework under construction in relation to the teaching and learning process of science and being an "educator".

Exchange of ideas, discussions, cooperation, collaborative research, confrontation of points of view, negotiations, consensus, and differences.

Mentor Teachers

Consolidated (but not concluded) framework in relation to the teaching and learning process of science and being an "educator".

Verbalization, sharing, communication

Learning community of teachers, sharing processes of reflection and dialogic communication in view of (1) KNOWING, (2) KNOWING-BEING, (3) KNOWING-DOING, and KNOWING-LIVING-TOGETHER IN A SOLIDARITY AND RESPONSIBLE WAY.

As we have already expressed, we will focus the argumentation and discussion of this article on the elaboration of reflective dialogic diaries. We speak of a “reflective diary” in the sense that various authors have conceptualized reflective writing after teaching action. Travé (1997) points out that the teacher’s diary is an instrument for analyzing the reflective thinking of teachers, both in training and in practice, which allows working on the problems of teaching practice with the aim of (re)constructing the teaching and learning process and evaluating it according to the context of the students. André and Darsie (1998) consider that the writing provided by the diary mobilizes reflections, awareness, and re-elaboration of knowledge and learning that favor the construction of new knowledge. Porlán and Martín (1997) also point to the use of the class diary as an aid to reflection on the most important processes of the dynamics in which the writer is immersed. By writing a diary, one is recording what one thinks, feels, and also how one perceives situations and one’s own thoughts.

In the same line of thought, Zabalza (1994, 2003) assumes that the teacher, by writing about their practice, reconstructs, through reflection, their professional activity and, from this, learns. This author also states that diaries are an excellent instrument for recognizing challenging issues, becoming aware of them, and making decisions about how to face them. In view of the contributions of the consulted authors, we understood that this work instrument would correspond to the pursued objectives and, therefore, decided to adopt it. However, the diary writing activity, consistent with the design, should also have a “dialogic” character. We bet on reflection, but, at the same time, on the need to communicate and dialogue with the Learning Community. That is, it is not an individual self-reflective process, but one shared and discussed with a group to which one belongs. In this sense, we believe we are making a contribution to the training processes that, in the concrete situation we analyze, have yielded some results. These dialogues in many situations were carried out face-to-face, but the use of virtual communication technology contributed to facilitating the dialogic process by streamlining the flow of diary submissions and, in many cases, also the responses to them. In the case of the situation being analyzed, we are dealing with two mentors and a group of nineteen practicing teachers. Not all had access to virtual communication means, but the vast majority did, some by having their own Internet access, but many by using this medium in the University environment itself.

In this work, the analysis is carried out based on fragments of journals from the students who interacted most with the author (all students sent their journals to both mentors, but communication was established especially between them and the teacher who participated in the guidance meetings of this). We have material corresponding to the work mediated by Paula, but, in view of the need to limit the extension, for this chapter we decided to focus on the group that we personally mediated and, within this, on seven students who were more spontaneous and detailed in writing. In recognition of the importance of the group in the realization and success of the learning community, we use the real names of the students cited (it was consulted and assumed as informed consent).

In this sense, a first aspect that we will highlight is the character of activity assumed with “enthusiasm”, without influencing the weight of an obligation imposed by discipline and fulfilled “bureaucratically”. We think that is why the writing of the journals is colloquial and affective. The willingness with which it was written is transparent, and above all, the awareness of the importance of establishing forms of communication that help to think and make one feel that one is not alone in a moment that is considered very important, challenging, and even feared. In Cristina’s message, which accompanies the sending of her first journal, she expresses her concern about sharing details of what she is doing and experiencing and waiting for the opinions of the mentor. But it also shows the space for creativity that she allows: thus, she refers to the innovations she has introduced in relation to what was agreed upon in the guidance meeting being observed and evaluated.

In the classic accompaniment of professional practice, in the space of our course, observation and guidance “visits” have always been carried out. But the number of students, the amount of work commitments of the mentors, and the fact that the practices are carried out in common schools far from each other and the university, make the number of visits very limited. The writing of the journal is in itself a valuable moment of reflection and self-evaluation; however, sending it to the mentors expands its validity and facilitates the dialogic process and joint construction between the mentee and the mentor. On several occasions, in the face of an interesting situation, this dialogue is directed towards the other classmates. This virtual dialogue will often be resumed in the “meetings of reflection and face-to-face and group dialogic communication” and in the conversations after the class visits.

One of the conceptions that the process proposes to address is to build an attitude of appreciation for the social importance of the teaching profession. In general, as already mentioned earlier, initial conceptions of understanding “being a teacher” as a possibility of work, provisional, to be used until one can work in the vocational field, that is, as a researcher in the biological sciences, have been used. And these two professional aspects are not seen as related, but rather one replacing the other.

This concept that devalues the teaching profession is linked, among other things, to conceptions of a teacher who “teaches” to disinterested students, or rather, only interested in passing the course without the intervention of the “real” construction of knowledge; a teacher who works on the content of a “ready” program, supported by a traditional textbook, all linked to academic and encyclopedic knowledge, unrelated to the interests and needs of the students. Unfortunately, these are the majority of the life snippets that come to the scene in the subject Didactics of Science when they are remembered. The training process proposes an “increase in professional self-esteem and consequently, having self-esteem in being a teacher”. This will have cause and effect relationships with “finding meaning” in assuming and committing to innovative conceptions and ways of working. That professional practice was a positive, motivating, and innovative experience was very important in the construction of these thoughts and feelings. But this is the first experience of prolonged work (they assume the leadership of a group for a two-month academic period), and that causes a lot of anxiety and fear. The journal was an ally in overcoming such sensations and allowed working with them:

I sat in front of the class, waiting for the teacher who was finishing. When he finished, the students left and found me sitting, waiting. Then, they came to me, kissed and hugged me; it was very emotional and also encouraged me and made me enter the class more confidently. (Cristina).

She was anxious, more excited, a reflection of that was the dream of the turbulent night that preceded the "big day". In that dream, I was in the class, in front of group 61 [a sixth year with which she does science practice] and when I tried to speak I realized that my mouth was glued, and the more I wanted to open my lips, the more they closed in an involuntary movement that reflected my insecurity. I confess that I was a little impressed with that dream and I told Claudette [the teacher of group 61] who reassured me. We both laughed a lot. (Juliana).

Both in Cristina's and Juliana's stories, those feelings of anxiety and fear can be perceived. Juliana's account is especially explicit and intimate and gave the opportunity to argue interestingly in one of the collective meetings. But it is also seen that both are interested and motivated, and the results of the experience were positive for them. The future teachers show this willingness to get to know the students; Juliana writes in her diary:

I asked the group (who listened to me in silence) to answer a brief questionnaire created by me with the aim of learning a little more about each of them, their interests, what they think about the science discipline. I gave them a few minutes to answer. The questions were as follows [the diary transcribes the questionnaire]. With the reading of the answers, which I did at home, I was able to draw a picture of the group. (Juliana).

Cristina also writes about her willingness to take the students into account, trying to establish intersubjective relationships that facilitate dialogue, the joint construction of knowledge:

The class began with my presentation to the group; I also told them that we would learn science together. Then I took attendance [the list of students] paying close attention to the name and appearance of each one I named, trying to learn a little about each one. (Cristina).

We see, therefore, that these diaries, prepared from the first class, were very significant as a way to help face a very special, and also difficult, moment in the training process of each student. In principle, for those who are already accustomed to the exercise of the profession, it may seem like one more stage to live, but if those first experiences are remembered, perhaps the emotional commitment they imply is understood. In this sense, the following fragment from Luciane is another example:

As a result of a very strong rain, this morning the group was reduced to just eight students out of the thirty that make it up. Although there were so few students, classes were not suspended; then it was time to start my practice. At the beginning, I was quite nervous, even having a "small audience". As the screening of a video was scheduled, we went to the projection room. I was very happy and more confident with the presence of my partner Milene, who asked to stay in the room because she wanted to watch the video, to later also show it to her group. She was there, in a little corner of the room, very quiet, but even so, I felt much stronger. (Luciane).

Luciane gives us arguments about the value of mutual support that is established in a learning community. This emotional speech has given us the opportunity to exemplify the theoretical foundation discussions on the subject, to discuss the concepts of solidarity, collaboration, mutual support. We consider that understanding this is fundamental. It is one of the main axes of the intended process and is an experience alien to the realities they have experienced: most of them know teachers working individually; the exchanges are usually during breaks, having coffee, hurriedly and lightly chatting. The bimonthly student evaluation meetings - "class councils" in Brazil - are, as a general rule, a sad counterexample of these collaboration concepts (focused on each one expressing the grades given and only exchanging ideas without a pedagogical spirit to intervene in problematic cases).

In some cases, the beginning of the activities confronts the students with situations that lead to negative feelings, of displeasure. This is the case of Karen and Daza, two highly motivated students who even opted for a project outside the classroom. This type of situation is eligible in one of the two practices, the other necessarily having to be in the classroom, in order to know the real work contexts. The intention of the project modality is to facilitate the experience of more innovative teaching and learning strategies. It was their case, they were willing to offer a course that linked Science and Environmental Education. On the date set to start the course, the school suspended classes due to torrential rain (it is a peripheral school with dirt access roads). The trainees were not notified, they arrived by taxi and had to return immediately. On the day set for the second meeting, a power grid failure leads to a new suspension:

We arrived at the school and there was a notice on the door stating that due to an electrical problem on the premises, it was impossible to hold classes and that all students were excused... We were very frustrated, as we were eager to see their little faces... We prepared ourselves as best as possible, having been idealizing this project for a long time, with the desire to "do something different for the lives of others." We just wanted a little more consideration... a phone call informing us of the situation... Next Thursday we will restart the course, hoping that this time there will be no rain or electrical inconvenience! But with the same desire to be teachers!!

A hug from the students Karen and Daza.

As we have already expressed, one of our concerns, in our role as advisors, is to help make this first practical experience a positive one, which leads, despite the known difficulties of real contexts, to not lose the enthusiasm for committed work. This is linked to the image of a teacher who is important in the lives of their students and for society. Sanmartí (2002) agrees with these objectives and comments on research regarding the influence of a satisfactory initial practice, as well as the first school in which the profession is practiced. These investigations prove that such situations have a very significant influence on the professional image and practice of the teacher. In this sense, when receiving the diary, we sent the following response:

Dear Karen and Daza:

I was saddened and understood the frustration. It was the first day of an important moment in your professional lives, and in which, both Paula and I know, you are putting a lot of enthusiasm and seriousness. However, try not to understand this as a frustration but as a lived experience that brings realism about the difficulties of school contexts. See that this does not lead to discouragement but to continue the struggle, with more realism, but without losing enthusiasm.

I hope for better luck this week!!! A kiss, María Inés.

We know that there are situations where the trainee loses control of the class. They are alone and have no one to help them think and decide on new ways to approach the management of a class situation that is not going well. In traditional practices, we have seen students who become increasingly distressed and "lost," and this often leads to failure. The reflective dialogic diary has been an important ally in providing support and solutions to these cases. In this sense, we highlight what has already been expressed about the authentic way in which the diary is written. The trainees have built the sense that this writing does not expose them to ridicule or censorship, but rather is the engine of a dialogue between colleagues, some with more experience than others, but all equally committed to the success of the work. Let's see what Francis writes about this:

There was a moment when two students started arguing and the whole group entered a state of generalized chaos. I yelled at them and separated the ones who were fighting. But with that chaos, I got lost and didn't know what I had to say or what I had already said... I became desperate!!! I grabbed the book to see if I could find myself and then the students were called to have a snack. Phew! Saved by the bell! (Francis).

Upon receiving Francis's diary, we were able to make personal contact with him and discuss and explain aspects of the work that had not been taken into account. The conversation was positive and contributed, as will be seen later, to Francis achieving good results in his practice. In the same sense, we will share what Juliana writes. In this excerpt from her diary, we do not address the narration of the situation of losing control of the class, but rather the reflection she elaborates after exchanges with the advisors and colleagues who give their opinion on her problem:

I thought a lot about this, especially after the meeting with the advisors and colleagues, and I already found my mistakes. In an attempt to win the group's sympathy, I think I was too friendly, too tolerant, not knowing how to assume my role as a teacher. The thin line that separates a flexible attitude from a complacent one is difficult to achieve, especially when we lack experience and self-confidence. Now that I have found the missteps, I still have time to retrace my steps a bit and reestablish mutual respect. I hope that in the next class I can abandon my role as a trainee and assume my place as a teacher in front of those 26 pairs of "hungry eyes" [Juliana uses this metaphorical form to refer to the willingness to learn that she recognizes in the students]. (Juliana).

Another aspect that we will highlight in relation to the contribution of the journals in the formation process is allowing each student to recreate, after coordinating the class, the narrative of all the activities carried out. This task of expressing in writing what has been done, helps in the process of thinking about what was achieved, as well as becoming aware of the difficulties encountered. And this serves to consolidate situations that are considered good and imagine new strategies that perfect the work. Also, these detailed explanations, when shared with the group members, are interesting aids to guide practice. Even narratives from previous years are used by the counselors as working materials with new groups. Let's see an example of these descriptions in a fragment of Juliana's journal:

I began to explore the students' knowledge of small land animals. I placed a large poster on the board with a representative drawing of a garden (made by me the day before) and asked what they were seeing. Answers such as "green area", "garden", "field", "natural environment", etc. emerged. Then I asked them to imagine a walk in that garden and, immediately, what small animals they normally find on a walk like that. Many participated spontaneously and as they said the name of an animal, I asked them where in the garden that animal was found. According to the answer, I stuck the figure of the animal in the indicated place. In addition, I questioned them about what they knew about that animal, its main characteristics. Some digressed, going off-topic and asking questions about other animals or about situations experienced at home, with pets. I paid attention to all the questions that arose and passed the question from one to another. Until some [students] surprised me with answers that went further than what I expected to hear from a sixth-grade group, so the topic deepened more than I anticipated. I also brought a photo of a flea and a louse, and the students were very impressed to see these animals in a large magnification. (Juliana).

This fragment can be analyzed in light of the theoretical foundation on current conceptions of science teaching, which were developed from the initial discipline (see Table 8.2). Without going into a deep analysis, we can mention that Juliana has in mind that students are not "blank slates", that they carry representations developed throughout their school and daily life, and that a constructivist teaching process must take them into account (Copello, 2000a). The journal also reflects her conception of knowledge construction as an encounter between the teacher, the students, and the knowledge they are working on (Copello, 1998b). When she expresses that "I paid attention to all the questions that arose and passed the question from one to another", we know that her performance is backed by conceptions about the elaboration of knowledge from social interaction and in the zone of proximal development (Copello, 2000b). Finally, we also highlight her statement "some [students] surprised me with answers that went further than what I expected to hear from a sixth-grade group", for its coherence with discussions held about the capacity demonstrated by students when given the opportunity to show it. Thus, we see that the dialogic reflection of the journals leads to another strategy: the integration between theoretical foundation and practice, that is, assuming practice as praxis.

In relation to the journals and their connection with the didactical conceptions worked on, we also share a response we give to a journal by Francis. He describes, down to the smallest details, how he guides the construction of the concept of species (we do not transcribe it due to the length of the text). By the way, this exemplifies the good work that a trainee who had initial difficulties can achieve.

Hello Francis:

I read your journal, it was a pleasure. I was even intrigued by your ability to detail everything so clearly. I think it was the product of your being very interested and putting a lot of dedication into your task as a teacher. Knowing you, and now reading your journal, I imagine you in the class and I know that the students must have enjoyed it a lot.

I found the way you were building the concept of species with the students very good and interesting. The only change I would suggest is that you would have taken one more step in the construction, changing the expression "pile". So, in the sentence you wrote on the board: "It is a pile of similar living beings, which can cross with each other and generate fertile offspring", I would replace "pile" with "set". The idea I propose is to accept their form of expression; the initial and most important thing is that they, with your help, construct the concept. Later we can propose some changes arguing that it is not because it is better, but to adapt to the written expression used in science. In any case, I find the construction process they did superb.

I hope to continue receiving all the journals like this! A hug, María Inés.

The journals reveal situations in which students face difficulties in organizing strategies to guide the learning process. And again, this is also a reason for interactions that provide support. Let's see in this sense what Luciane expresses:

Although I was calmer in this class and better mastering the content, I don't think it was a very motivating class; some students seemed like they weren't even present, such was their distraction, they asked few questions and I think they showed no curiosity. When I looked at the students, it seemed like they were telling me: "Theoretical class, how boring!" (Luciane).

In the case of Luciane, we are faced with a very critical student, who demands a lot from herself and therefore is able to perceive very clearly the drawbacks of the work she does. She will achieve fully acceptable moments in the course of her practice, but other moments, like this one, frustrate her. The classes she refers to in the previous excerpt are the fifth and sixth (two combined periods). In the next class, she tries to reverse the students' disinterest by organizing a practical class. In this way, she titles her journals:

5th and 6th class: "Theoretical class, how boring!"
7th and 8th class: "Practical class: awakening interest"

In the guidance meeting, we analyzed these issues with Luciane, agreed on the importance of working on the connection between practice and theory, and arrived at the challenge of organizing theoretical classes that were also motivating.

We visited her class the following week and witnessed an excellent theoretical class in which the students participated a lot, were interested, and actively contributed to the construction of the knowledge being worked on.

An aspect, seemingly minor, such as the narration of group organization strategies, implies conceptions that can be discussed and lead to interesting arguments. In this sense, this excerpt from Vanusa allows for dialogue regarding the stimulation of social interaction and its role in the construction of knowledge:

I counted how many students were in the class, there were 25. So I asked them to form 5 groups of 5 students and for each group to join two small tables and sit around them. After forming the groups, I distributed to each one an envelope with several cut-out figures with drawings of the living beings we were going to study (fungi, protozoa, and bacteria). (Vanusa).

One last excerpt that we will include brings to the scene another aspect that is very worked on, which is the conception of evaluation. The way of guiding the teaching and learning process and the evaluation process must be coherent and support each other. This leads to understanding evaluation from the perspective of regulating the learning of students and also the teaching by the faculty. However, this is not what is practiced in school; there, an evaluation that only certifies and classifies still prevails (Copello, 2001). Thus, students at the end of the practice have to “apply a test” and deliver “classifying grades.” Any other evaluative activity is unknown to them. This mismatch of visions generates tensions and situations that have to be discussed. Francis, in one of her journals, includes the following narrative:

I asked the students to organize themselves into groups of four people to carry out a practical activity. Immediately the students asked: “Is it group work? What grade is it worth?” I don’t know if I acted correctly. I took advantage of the students’ concern with the grade and said that I would talk to Claudia [the group’s teacher] to give some points to all the students if they participated well in the activity, but it would be a grade for the group and they would only receive it if everyone collaborated. I got it right! The group accepted the activity and participated actively. (Francis).

After reading her journal, we sent the following response:

Francis, as you know, we have discussed that it is important to stimulate the students’ performance through intrinsic motivation with the activity and not because of a grade. And that we have to invest efforts in building in them the conception of an evaluative process that is mainly concerned with telling them “how they are doing” (regulating learning). However, we also know that students are not used to working within these conceptions. That’s why I think you did well and it was interesting and very good to establish a collective commitment. (María Inés).

The wealth provided by the analysis of the journals leads us to recall several other aspects that could be analyzed from them. For example, a practice that we consider fundamental is the participation of the coordinating teachers of each group in the work, in order to establish a triangle that includes the guiding teacher, student teachers, and the coordinating teacher of the group. This is related to the connection between initial and ongoing training processes, one of the conceptions present in the training model and that we have also sought to put into practice. However, the inclusion of the group’s teacher was not as deep as we had thought in theory. We believe that this is still an open path and in which we must invest theoretical and practical efforts (including reformulating the conception presented in Table 8.5, in order to include their presence in that triangle).

The analysis presented in this chapter aims to bring readers closer to sharing the spirit of the work. We understand teacher training as a learning community committed to the common goal of building a critical and well-founded teacher-educator, who values their professional practice and knows and needs to move away from individualistic work and join a group where collaboration and mutual support exist.

8.6 Inviting to Participate: Suggestions for Didactical Activities

This text recounts and analyzes aspects of a didactical activity, applied for 6 years, in the process of training natural science teachers. Given the available length for the chapter, it was not possible to detail the entire process or discuss its comprehensive application. However, the text aimed to outline the didactical process worked on, discuss some main features of its foundations, and analyze aspects of its application in the last year of the three involved in its realization.

As we have already explained, this didactical strategy was conceived, analyzed, and evaluated in a continuous training work for biology teachers (Copello, 1998a; Copello & Sanmartí, 2001a). Between 1998 and the present, it has been applied in initial training and, concomitantly, collecting data for analysis and evaluation of its adequacy at this level. The results obtained, although still in the analysis phase, indicate that this model is a way to advance in the training of better-prepared teachers to face the challenges of today's school and society.

Although this text did not choose to highlight these aspects, the mutual influence between the initial and ongoing training processes of teachers is also being investigated, as well as the connection of both in the "environmentalization" of the school curriculum and teacher training (Copello, 2003; Pujol, 1998, 2001; Sanmartí & Pujol, 2002). We emphasize that those readers interested in thinking and working on the connection of Environmental Education in the curricular renewal of the school and in the training of teachers can also find possible connections in the text.

In order to be more explicit in the didactical orientation that the whole book proposes, we will detail the spaces where we find the application of this work interesting:

- Reflections and suggestions for guiding teachers of scientific teacher training courses.
- Reflections and suggestions for guiding teachers of other teacher training courses.
- Use in different subjects of teacher training courses. Reading and discussing with student teachers all or part of the text.

We reiterate that this is not something "finished", a "recipe" to apply. What we intended is to share with readers aspects of experiences that we consider interesting and, above all, that have given us satisfaction. We are available to all colleagues, teachers, and student teachers who may wish to interact with this text. We are confident that this interaction could bring interesting innovations.

Annotated Bibliography The annotated texts are intended as suggestions for complementary readings to deepen the topic addressed. The selection criteria were: (1) direct link with the topic discussed, (2) understanding them at a level of comprehension accessible to the students of the faculty, and 3) ease of obtaining them.

- Copello, M. I. (2002). Didáctica: un compromiso con el conocimiento biológico escolar significativo y relevante para la vida. *Pensamiento Educativo, 30*, 271–294. This article is a complement to the present one, since it discusses the application of the same teacher training model at the beginning of the process, that is, in the Science Didactics course.

- Orellana, I. (2002). La estrategia pedagógica de la comunidad de aprendizaje, definiendo sus fundamentos, sus prácticas y su pertinencia en educación ambiental, en Sauvé, L., Orellana, I. y Sato, M., *Textos escogidos en Educación Ambiental, de una América a la otra,* Tomo 2, ERE-UQAM, Université du Québec, Montreal. Versions are available on the WEB.
- Porlán, R., y Martín, J. (1997). *El diario del profesor: un recurso para la investigación en el aula.* Sevilla: Editora Díada. Short, easy-to-read text that addresses essential aspects of the journal as a tool for analyzing the teacher's practice.
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- Sanmartí, N., y Pujol, R.M. (2002). ¿Qué comporta capacitar para la acción? *Investigación en la Escuela, 46*, 49–54. It contributes to clarify conceptions of school environmentalization. As we have already expressed, even if this particular conception is not worked on, we consider it an indispensable background for teacher training processes.
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Chapter 9
Pre-service Science Teacher Education in Colombia

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9.1 Introduction

The present text is the result of research projects developed during the years 2002 and 2003 respectively. In them, the epistemological, didactical, and pedagogical foundations from which the initial training academic programs that had previously received accreditation from the Ministry of National Education were investigated, guided said training.

The study examined the official documents of 22 programs, out of the 51 that received mandatory prior accreditation. For this purpose, three matrices were designed, one for the epistemological, another for the didactical, and the third for the pedagogical. In order to complement the previous information, interviews were conducted with the heads or directors of the programs, the professors of the same, and the students enrolled in them.

The aim was to identify the epistemological approaches, the location or not of these programs in didactics of sciences, their formulation or not within the research field characterized as that of initial and continuous training of science teachers, and the precision or not of what, for the purpose of the projects, was stipulated as science pedagogy. Special attention was paid to the bibliographic references, taken from specialized journals, which supported the curricular proposals.

It should be clarified that, in Colombia, the initial training of science teachers is carried out by the faculties of education of the various universities. Currently and

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since 1998, the duration of this university degree is five (5) years or ten (10) academic semesters. The professional title is that of a Bachelor in the respective area. Special mention deserves the case of the National Pedagogical University, dedicated exclusively to the training of undergraduate and graduate teachers in sciences, mathematics, arts, and technologies.

Based on the results obtained and in accordance with the bibliographic review carried out, the IREC Group has formulated a proposal for the initial training of science teachers (Gallego Badillo & Gallego Torres, 2003) which, in the context of Colombia, is about to be subjected to contrast, both by national specialists and by Ibero-American ones. This proposal is included in the present text.

9.2 On the Epistemological Aspects

In accordance with the proposal that didactics of science has been based on epistemological analysis (Adúriz-Bravo & Izquierdo, 2002), particularly from constructivist approaches, it has become necessary that any examination or formulation of a science teacher training program must revolve around this issue. The word "episteme" derives from the Greek words "epi", on, and "stemai", erect, so it initially meant to stand erect on, to stand on a solid base. Aristotle in his Metaphysics identifies it, along with "techné", as apodictic knowledge, that is, knowledge that requires demonstration. The Romans translated it as "scientiae", science. According to the Stagirite, they are knowledge because they are teachable. When people from experimental sciences with philosophical interests began to ask about the nature of these sciences, the philosophy of science was abandoned and replaced by epistemology. Hence, epistemologists study the internal constitution and historical development of these experimental sciences.

The approach to the epistemological must be carried out from a general perspective, as well as necessarily from a specific one. The first, because it is essential to establish reference frameworks related to the conception of science and the vision of its historical development. In this sense, empiricist (Bacon, 1979), positivist (Comte, 1984), rationalist (Bachelard, 1978), deductivist-constructivist (Gallego Badillo, 1997), or eclectic (Gallego Badillo & Pérez Miranda, 2002) (Amador-Rodríguez et al., 2021, 2023) perspectives must be specified.

This general epistemological analysis must also focus on the specification of the concepts of theory (Popper, 1962), paradigm (Kuhn, 1972), and research programs (Lakatos, 1983), with the purpose of elaborating an alternative explanation to the empiricist-positivist approaches, in which the development of sciences is explained by resorting to inductive logic and in which the idea that it has been a linear and cumulative process of discoveries prevails.

Inside the IREC Group and in accordance with specific bibliographic reviews (Izquierdo, 2000), it has been concluded that the epistemological concepts of theory, paradigm, and scientific research program are exclusive, according to the theoretical specifications that delimit them. Consequently, and taking into account the scientific status of science education, the concept of scientific model has been worked on. In this regard and in accordance with the bibliographic review (Caldin, 2002; Del Re, 2000; Kretzenbacher, 2003), a synthesis of what is currently under discussion regarding what is conceived as a scientific model is as follows:

- The construction of models or "modeling" by different specialist communities has been a predominant necessity.
- There is plurality around what each epistemologist conceptualizes in relation to the category of model.
- There is consensus around the idea that every model is an abstract representation of the set of interactions that are conceptually and methodologically delimited as an object of knowledge.
- The structure of a scientific model must be different from the descriptions of the facts or phenomena that it links inferentially.
- Classifications of models have been established, ranging from taxa such as mathematical and physical, to those that place them as iconic, symbolic, or analogical.
- Some thinkers conceptualize them as intermediaries between theoretical assumptions and the realm of scientific praxis itself, in the sense that designing and conducting experiments with a view to indispensable empirical contrasts requires the development of appropriate models.
- It is common in corresponding studies to conclude that many models are models of models, among which hierarchies can be established.

Given that the central problem is the version of science that underlies teacher training and, therefore, the one that is intended to be socialized in the majority of the school population in Latin America, the general epistemological analysis must address reflections related to the fact that since the First Industrial Revolution (Kemp, 1986), the system of science production and the industrial system became intertwined. Therefore, a rigorous analysis must be made of the fact that the products of scientific research, in general, and of technology, have become commodities; a category from which the specialized information itself should be examined (Di Trocchio, 1995). In other words, the scientific activity of knowledge production of each of the specialist communities is committed to the system of production of goods and services from which the financing of said activity is derived. Regarding the specific epistemological analysis, from any of the admissions of the historical development of the sciences, it is explainable taking into account the concepts of theory, paradigm, research program, or scientific model, such analysis must specify, within the deductivist-constructivist approach, what is questioned below.

What is the conceptual and methodological structure of the scientific model that is the object of work in the classroom? What are the mathematical foundations of the concepts that delimit it (Mosterín, 1978)? What is the space of explanation and description to which it refers? What is the internal logic of its conceptual and methodological structure? What interactions do they specify? What problems can be formulated and solved? What questions does it prohibit? From a historical perspective, what were the problems that were formulated from its conceptual and methodological structure, whose solutions were not satisfactory for the respective specialist community, to the point that it became necessary to formulate another theory, paradigm, research program, or substitute scientific model? It is from this reflection that the reason is given for why those theories, paradigms, research programs, or scientific models already identified necessarily must be the object of curricular planning in terms of science education for all.

9.3 On Didactics of Science

The term didactics first appears, between 1612 and 1618, in the writings of the German Wolfgang Ratke (1571–1635), in which he defines it as a set of rules to guide teaching; Ratke called himself "didacticus." The Greeks spoke of didaxis, giving and receiving the lesson, by the "didascalos," the primary school teacher. It seems that John Amos Comenius (1592–1670) became aware of Ratke's writings during his time at the University of Heidelberg. If this happened, he developed in depth the German proposal in his work *Didactica Magna*, which was published in 1657. In it, he defines didactics as "the art of teaching everything to everyone, saving time and effort."

What did Comenius mean by the word art? As it will be recalled, the Latins also translated the Greek word "techné" as "ars", from which the corresponding Spanish words, art and artisan, come.

The Greeks distinguished two classes of arts, the noble ones, typical of aristocrats, and the ignoble or mechanical ones, practiced by slaves. The latter, said Hippocrates, were learned by observation and imitation, with little participation of the intellect.

It is often stated that, in Rome, faced with the competition born between slaves and foreigners, in relation to the practice of trades, Emperor Numa regulated these practices by creating the guilds of artisans. Thus, the guilds of coppersmiths, silversmiths, carpenters, and others of the same lineage emerged. With the historical development of these guilds, within each of them, the "Collegia Artificum", the colleges of artisans, made up of master artisans and disciples (Manocorda, 1987), emerged. The word master is derived from the Latin "ma-struere", the chief builder (struere, to build).

According to the above, Comenius' use of the term art would not refer to the occupation of master artisans, since in his work Pampaedia, he argues that "teachers" should not worry about what to teach and how to do it, as it has been previously determined by others. It should also be noted that Comenius is the initiator of didactical texts. Comenius' teacher is a worker. It should be noted, in passing, that even in some initial teacher training programs for science teachers, the teaching profession is learned in academic spaces called teaching practices by observation and imitation of what the teachers of the associated or cooperating educational institutions do. A critical analysis of the *Didactica Magna* allows us to conclude that Comenius' thought is of an empiricist nature, based on the proposal of F. Bacon (1979), of whom he was a friend, to the point that, being the latter Lord Chancellor of

England, he proposed to Comenius to advance an educational reform, which was not possible to carry out. This conception of didactics, with the necessary modifications, lasted, in some cases, until the second half of the twentieth century, when, in the field of science teaching, professionals from the same field made this teaching the object of research. It should be pointed out that, from an empiropositivist approach, sociologists and educational psychologists turned these disciplines into the sciences of education, leaving aside didactics and pedagogy.

The current formulation of didactics of science, as a scientific discipline (Sanmatí & Izquierdo, 2001), has antecedents that are essential to specify, focusing on both the scientific revolution carried out at the end of the nineteenth century and the beginning of the twentieth century, as well as the epistemological revolution it caused. Without these new perspectives, what is called here the "didactics of experimental/natural sciences" would not have been created after the 1960s, which has gradually been consolidating as the science of teaching sciences, even though in many teacher training institutions this development is not even suspected.

When talking about the scientific revolution, using the expression of T. S. Kuhn (1972), it is necessary to focus on the changes in the conception of science and scientific practice that occurred during those years of change of the century. It is known that by the middle of the nineteenth century, three mathematicians Bolyay, Riemann, and Lobachevsky, reread Euclid's geometry, recorded in his Elements, the interpretation they made of the postulate of parallels led to the establishment that this was true if the world was flat, but if it was spherical or curved, it was not, so this postulate was valid for that condition. The conclusions were consistent and led to the conviction of the limitations of all knowledge. Validity is limited to what is made the object of knowledge, so asking a theory about problems that are outside its conceptual and methodological scope means thinking outside of it. The conviction emerges that no knowledge is universally valid and therefore non-Euclidean geometries are constructed.

When Albert Einstein reads Newtonian dynamics from Riemann's geometry, he questions the postulates of absolute time and space and simultaneity, and focuses on the movements of objects approaching the speed of light, concluding that a new theory was required. He then formulates the general and special theories of relativity, which limit the Newtonian conceptions and explanations about the world view; and, again, it is confirmed that every scientific theory is valid in its conceptual and methodological context. It is significant to think about how Einstein, to explain the gravitation of planets around the sun, denies the Newtonian principle of mechanical equilibrium, specifying that the concept of force does not exist for this case, since he establishes that each planet takes the curvature of space-time created by the presence of the corresponding star, in that space-time. These are two different explanations from different hypothetical-deductive bodies. What truth is taught in school?

On the other hand, and more generally, it would also be necessary to consider what happened when the world of the atom was attempted to be explained from the Newtonian perspective, finding that it was not applicable and that a new vision had to be created; from this, quantum mechanics emerged, so it would be necessary to examine historically the problem of how models about the atom are formulated, which are valid in a certain period, only to be later abandoned and replaced by others. It could be said that there is a crisis in relation to the development of sciences and scientific knowledge; a crisis that forces many science workers with philosophical interests to develop answers to the questions: What is science? How does scientific knowledge develop?

It is in this context that different European countries, including Spain, professionals trained in the sciences decide to take on the problem of teaching them in the new historical epistemological framework and outside of what is established by the alphabet programs (Novak, 1988) and from the perspective of a didactics of science that would have to address the teaching of them as a problem of theoretical construction. With the development of research in this area, the problem and, therefore, the field of knowledge called "initial and continuous training of science teachers" also emerged.

The new non-inductivist epistemological perspectives allowed the formulation of constructivist approaches. These approaches cannot be assumed generally, as two currents emerged: the so-called radical constructivism, by Von Glasersfeld, and the one known as moderate constructivism. In the latter, a group of men and women whose training would have taken place within the experimental sciences, made the teaching of these a rigorous field of research, distancing themselves from the usual conceptions. Moderate constructivism became an "emerging consensus" (Novak, 1988), launching a series of critical reviews (Gil Pérez et al., 1999a, 2002).

The first proposal was made based on the evolutionary epistemology of S. Toulmin (1977), assuming didactics of science as a rational enterprise (Aliberas et al., 1989). Later, Hodson (1992), given the state of research in this discipline at the beginning of the nineties, proposed that it was already possible to integrate it as a body of specific knowledge. A third version is that of the fields of knowledge (Gil Pérez et al., 1999b). Thus, it is argued today that there is a scientific community that has delimited fields of knowledge, within which they advance their research (Gil Pérez et al., 1999b). The emergence of this didactics of science will also be argued by bringing up the publication of Handbooks; specialized journals; international cooperation programs among the various researchers; postgraduate training, including post-doctoral training, which, in increasing numbers, is offered by different universities in most countries; in addition to congresses, symposia, and other similar modalities of meetings of specialists.

9.4 Teachability and Teaching as Didactical Problems

Although previous attempts at conceptualization were made (Gallego Badillo & Pérez Miranda, 1999), it is proposed that the problem of the teachability of a science, in general, and specifically of its theories, paradigms, or scientific models, would be formulated and solved from what a group of French specialists in mathematics education have called didactical transposition (Chevallard, 1985) or the English didactical recontextualization; proposals that have been recently taken up in research within the science of teaching sciences. Resorting to transposition or recontextualization must start from the fact that the history of the development of scientific knowledge has a different logic from that of mathematical knowledge.

There are three elements that influence the transposition or recontextualization of a theory, paradigm, or scientific model: the interpretation of the originals in which it was proposed, developed, and accepted by the scientific community; the epistemological, general and specific, didactical and pedagogical conceptions of the person making the transposition or recontextualization; and, the curricular intentions of the degree and level of the educational system. It is asserted that in the process, it is essential to establish strict epistemological vigilance (Kang & Kilpatrick, 1992), which must also be historical.

The transposition or recontextualization of theories, paradigms, or scientific models of a science generally give rise to teaching texts for different levels of the educational system. In these texts, the author(s) can organize chapters or thematic units of theories, paradigms, or models that they freely consider, following or not the historical order of the development of that science. They can also arrange the content according to their epistemological, didactical, and pedagogical conceptions of that science version. It should be noted that the usual practice of science teachers' performance has been framed in the use of teaching texts. In this procedure, as a non-linear consequence of the training programs from which they graduate, they often uncritically follow the truths of the authors of such texts (Sanmartí, 2000).

Regarding teaching and, in particular, the paradigms that have been dominating, a starting examination would have to review the analysis carried out by Daniel Gil Pérez (1983). Paraphrasing Professor Gil Pérez (1991), the belief that teaching is easy still seems to dominate in initial science teacher training programs and other programs, to the point that anyone, relying on their experience, can do it. This is a teaching reduced to prohibitions and recommendations, from which the person who takes up the profession considers it as paradigmatic, in a closed environment where criticism is not accepted, and experiences are not subjected to the examination of their possible successes or failures.

Another point of view is the one assumed from didactics of science. Teaching as a didactical problem and taking into account the methodological version (Gil Pérez et al., 1999a; Gil-Pérez et al., 2002) of it, theoretically grounded, which leaves aside the algorithmic or instrumental reduction of following the scientific method or the Comenian conception that didactics is the art of teaching, proposes that as methodological, teaching derives from the didactical assumptions from which the transposition or recontextualization is made; assumptions that necessarily are formulated hypothetically following the guidelines of the didactics of science. Teaching, then, is specified in strategies through which the collective classroom seeks to contrast such assumptions; a contrast that is also formulated and put into practice in the search for empirical support for the didactical model that underpins the scientific work of the didactician of that science that he makes the subject of work in the classroom.

Within the scientific approach proposed here, which makes the performance of the science teacher a researcher and member of the community of specialists, it is necessary to delimit what is meant by teaching strategies. It should be said that they must have as their horizon of meaning, making each course, subject, seminar, workshop, or academic space, a collective classroom. The performance and application of instruments for collecting valid and reliable information must also serve the purpose of summoning students to work on each transposed or recontextualized theory, paradigm, or scientific model.

This different conception of teaching abandons, to reiterate, the usual verbal transmission of curricular content and the algorithmic and instrumental reduction typical of didactics as the art of teaching. It is specified that, when talking about strategies, given the intentionality of conceptual, methodological, attitudinal, and axiological change (Gallego Badillo et al., 2004), each change elaborated by the students means a new starting point that requires the reformulation of the initially formulated strategies and that each group, to the extent of the process in which they commit and involve, will require the corresponding reformulations. There is no single formula previously articulated for all students from different social and cultural contexts, except within the paradigm of transmission-repetition of curricular content. The didactician of science necessarily has to be creative and resourceful.

In this context, the problem of contrasting didactical assumptions requires the community of specialists to develop and epistemologically support a different proposal, given that the classroom collective created by teaching strategies is expected to behave in a non-linear and complex manner; in other words, it is necessary to definitively abandon both empiricist-positivist and experimentalist approaches. Within this perspective related to methodology, it would be necessary to review the criticisms made by some specialists to the foundations of research carried out in the field of students' alternative conceptions (Moreira, 1994; Solano et al., 2000). The alternative conceptions of students as a field of knowledge and research within didactics of science (Furió, 1996; Pozo, 1996) can be supported by the results obtained, which is already a kind of basic knowledge (Kuhn, 1972; Lakatos, 1983), whose recognition introduces, indispensably, criticisms of the usual paradigms and whose ignorance is characteristic of the transmission and repetition of curricular content. In this field, specific research has been carried out, as it has dealt with theories, models, or specific concepts. The interested reader can refer to specialized journals.

This field has a history of conceptual and methodological transformations since it was established that students did not enter the process in a state of absolute ignorance concerning what the curricular content accounts for. These initial ideas were first called preconcepts, then conceptual errors, and so on. Historical-epistemological and didactical critique of such considerations led to the validation of these initial ideas, to the point of calling them "alternative conceptions."

9.5 Science Teachers' Conceptions

Research in this field has a long history. In particular, the works on epistemological, pedagogical, and didactical ideas (Gallego Badillo & Pérez Miranda, 2002) are highlighted, and derived from these investigations, research in the area of the nature of science (NOS) has been proposed and developed (Amador-Rodríguez et al., 2021, 2023) preceded by more extensive works (Porlán, 1989), which inaugurated the general field identified as “teacher thinking” (Gallego Arrufat, 1991). A critical review of these investigations can be found in N. G. Lederman (1992).

Specifying what is referred to as epistemological, didactical, and pedagogical conceptions of science teachers, the non-linear origin of these could be found in the initial and ongoing training programs from which they come or to which they belong; in the rationalization of their experiences as teachers; in agreements with colleagues’ ideas; in the estimation they have of their professional practice; in the beliefs circulating in the social and cultural environment; or, as a more or less elaborated amalgam of all the previous ones. The conclusions derived from research in this field indicate that, in general, science teachers act in the classroom according to their conceptions.

As for epistemological conceptions – in specific cases, they should be identified and characterized – they can be of an empiricist-positivist nature, influenced by uncritical acceptance of the scientific method, or by a rigorous approach to deductivist-constructivist positions (Gallego Badillo & Pérez Miranda, 2002). In this case, being a supporter of the idea that scientific knowledge is a historical and communal construction, it is not admitted that it is constituted by absolute truths and that its development is explained by the substitution of theories, paradigmatic changes, the abandonment of research programs, or the substitution of scientific models.

Didactical conceptions, to some extent in solidarity with epistemological ones, and also in specific cases, require rigorous identification and characterization, as they could be based on the usual paradigm that knowing a science is enough to teach it and on the oral transmission of curricular content for a rote and verbatim repetition of such content or, on the contrary, inscribed in didactics of science in which teaching is assumed as a problem.

Pedagogical conceptions, as a set of well-intentioned recommendations; maintaining that the sciences of education are educational psychology and sociology; and proposing that pedagogy is the science of education, with Comenian-type didactics, in which this didactics is the methodical part of that pedagogy. From another perspective, such scientific pedagogy, closely related to didactics, and therefore, the pedagogical conceptions of teachers focus on formulating the problems that have to do with the meaning of science education at all levels of the educational system, the educational aspect of the sciences and the educability that is fostered with them, all in the context of producing a critical belonging of the new generations to the current society affected by the products of scientific research.

9.6 The Reliability of Teaching Texts

Some initial questions: Is there a correspondence between the historical development of each science and the structure in chapters or thematic units presented by teaching texts? Is it feasible for the didact to develop another organization? From where to start formulating the problem of the reliability of such texts? What kind of science do these texts circulate and for what social, cultural, political, and economic contexts? What problematic fields give rise to such reliability?

The first of these fields arises with the historical review carried out by.

T. S. Kuhn (1972). It is from him that texts become the object of criticism. This physicist and epistemologist highlights that the texts contained only a historiography of the knowledge production process, without resorting to a methodology specific to the investigations of that history, so that, at most, they were only a poorly told history, in which revolutions in scientific ideas and practices were, strangely, left aside. From this perspective, a succession of themes is usually presented in the texts, without referring to such changes in conceptions and scientific practices, which occurred due to the formulation of theories or scientific models that replaced those on which the currently considered developments were based. Thus examined, teaching texts impose on teachers and learners the belief that this development has been linear and cumulative.

The second field, in relation to the previous one, argues that these texts are elaborated from empiricist-positivist epistemological versions or from eclectic conceptions (Amador-Rodríguez, 2018), in which the science they deal with is reduced to mere descriptions of facts and phenomena, since their authors think, in the Baconian way, that these constitute the objective of it. Observing and describing, within such a view, constitutes the foundation of the process for producing knowledge. The explanatory and theorizing exercise is the introduction of subjectivity which, by principle, is equivocal within this approach.

The third problematic field refers to the possible conceptual errors that such texts may contain, from the critical examination made by scientists working in the production of knowledge and the empirical support that underlies each of the themes addressed by such texts. Consider, for example, that recently those who cloned Dolly the sheep, noted on sexual reproduction, that some textbooks contained errors, due to deliberate and consensual simplifications or the confused knowledge of their authors (Wilmut et al., 2000).

The analysis of the reliability of teaching texts is of old origin. However, with the introduction of the problem of didactical transposition or recontextualization, this analysis undergoes, especially in the field of experimental sciences, a reconceptualization (De la Gándara et al., 2002; Perales & Jiménez, 2002; González et al., 2003). Also, consider the epistemological, didactical, and pedagogical problem introduced by the translation of texts published in another language, in which the science that is made the object of teaching is a version, of the version, of the version, with the timelessness that this implies, that is, its anachronism which, of course, in the case of texts based on other teaching texts, the science they contain is, in the same way, a version, of the version, of the version, of the version: fourth-hand science.

9.7 The Problem of Evaluation

The concept of assessment in didactics of science emphasizes that it does not refer to the usual act of grading and that this practice is linked to the epistemological, didactical, and pedagogical conceptions of teachers. Within an education based on curricular projects, assessment is based on the conceptual and methodological frameworks from which each project, in a hypothetical-deductive manner, subjects them to rigorous contrast in classroom practice; this necessarily means that these foundations are not assumed as absolute truths. Consequently, every curricular project is formulated and developed in terms of epistemological, didactical, and pedagogical reconstruction of the starting foundations (Stenhouse, 1991).

Assessment, thus conceived, becomes complex, as it must collect valid and reliable information, with instruments specifically designed for this purpose. In this way, formulating and implementing a curricular project constitutes an exercise in delimitation and foresight that predicts what future results could become its empirical supports, and within which learning assessments, outside of job training, are just one of its connotations.

In the daily practice of educational institutions that follow the usual paradigm, even if the word is mentioned, assessment is a sophism of distraction, so science teachers, after practicing verbal content transmission and carrying out some typical pencil and paper exercises assigned at the end of the teaching text they follow, carry out an exam or test whose results, in terms of grades, do not revert to the didactical process advanced; that is, on the foundations of their teaching professionalism. Explanations of the results are often intuitively attributed to students' abilities. Within the constitution of didactics of science, assessment has been the subject of reflection and investigative work, to the point that it has become clear that assessing is not grading (Alonso et al., 1996), since any assessment proposal must conceptually and methodologically detach itself from teaching strategies, so there is no justification for teaching that does not consider the results of this process as empirical contrast of the same (Pozo, 1992). In this line of thought, it has been argued that assessment is an opportunity offered to each student to continue their process of conceptual, methodological, attitudinal, and axiological change (Gallego Badillo & Pérez Miranda, 1997), that is, to review themselves in relation to the classroom collective developments and in comparison with what is accepted by the community of specialists.

It would be necessary to revisit the proposal of assessment as regulation and self-regulation (Jorba, & Sanmarí, 1996), which combines the ideas of external judgment with those of internal judgment. In this perspective, regulations would be from the science teacher and other members of the classroom collective, regarding what is accepted by specialists, teachers, and knowledge producers; and self-regulation assumed by each student in the face of such external agreements. It is believed here that this concept of assessment is logically integrated into the process of constituting didactics of science as a conceptually and methodologically grounded discipline.

9.8 Pre- and In-service Science Teacher Education

This field is not independent of the others in which specialists in didactics of science currently work. In this regard, it is necessary to mention an article considered paradigmatic by some, whose author is the renowned specialist Daniel Gil Pérez (1991) and which must be interpreted from the perspective of didactics. Professor Gil Pérez asks and answers about what science teachers need to know and be able to do, that is, about the construction of the foundations of their professionalism, in terms of training that enables them to structure that knowledge and know-how within a hypothetical-deductive perspective. As for what they need to know, by conviction and not by imposition, the proposal of Professor Gil Pérez is shared, in the first instance, to know the science that they will make the object of work in the classroom with their students; a knowledge built from the general and specific historical-epistemological analyses of those theories or scientific models that, following the rationality of the conceptual and methodological foundations of the initial training curricular project, are also made the object of work in the classroom with future colleagues. As expected, this knowledge does not cover all theories or models, but it must enable a professional attitude to continue dealing with such studies. This is the difference that makes the process separate from any judgment based on the numerical accounting of science subjects established in the study plan.

A science teacher with such training is able to account for the origin of each theory or model; the internal logic of its conceptual and methodological structure; the necessary support from other disciplines; the problems that can be formulated and solved within it; the one that was replaced because its solutions were not accepted by the community of specialists and led to its abandonment and the consequent formulation of the substitute. In the same way, the basic knowledge collected and incorporated in the new one, the questions that are prohibited within the delimitation of the interactions that it descriptively and explanatorily accounts for, and which constitute its object of knowledge and research. The historical-epistemological study is the one that allows, in turn, to account for the validity or not of each theory or model, placing it in its proper perspective within the development of scientific knowledge and from where a didactical justification of its necessary presence in a curricular project will derive, in accordance with the level and grade of the educational system in question and within which it deploys its professional performances.

The selection of theories or models that must be made the object of historical-epistemological, didactical, and pedagogical work with those who begin their training as science teachers requires, first of all, a methodological agreement with the conceptual foundations of the curricular project. Secondly, a mastery, also historical-epistemological on the part of the project formulators, from the intentionality of constructing the reasons why the development of scientific knowledge followed that alternative and not another; that is, why among all the proposals, the community of specialists admitted the one that came to regulate scientific practice.

What science teachers need to know and be able to do must also contemplate a historical-epistemological construction of the development of didactical knowledge and, in this order, be able to account for the reasons why and from where the foundation of their professionalism became a conceptually and methodologically grounded discipline; a construction in which they develop the conviction that it is an area in permanent transformation. What a person who begins their training as a didactician of science needs to know in didactics of science, to reiterate, is given by the brief description of the fields that have been made in this chapter. In accordance with the following discussion, an integral proposal is presented on how a curricular project could be structured that incorporates current developments in didactics of science, including a version about the pedagogy of the same.

9.9 A "Pedagogy" of Science

It is admitted here that pedagogues are concerned with studying education, a phenomenon that they classify by its foundations and characteristics into two. The first, called natural or spontaneous, is that which occurs within a community, without the existence of educational institutions or educators who professionally perform such a task. It can be said that it is the parents and the family context first, then the community in general, who are responsible for making the new generations belong to the collective; a belonging that is achieved through the learning of language, customs, rites, assumptions and beliefs about nature and society, the norms that regulate it, and the learning of trades, through observation and imitation, through which each one ensures their subsistence.

The second, the artificial or curricularized one, with educational institutions and educators who work in an approximation of the new generations to the pedagogized academic knowledge, within an educational system divided into levels and grades, which obeys a specifically formulated and accepted social, cultural, political, and economic project by the majority without exclusion, in principle, of minorities. It is within this education that the need to socialize the elaborations produced by the different scientific communities is introduced.

9.10 Didactics of Science

The standard English expression "science education" should be taken as equivalent to "didactics of science" as used in this book. The questions, again, that pose the problems inquire about what is meant by educating in science and being educated in these disciplines. Of course, the formulation and solution of these will depend, first of all, on the historical-epistemological approach and, secondly, on the social, cultural, political, and economic project that establishes the curricular intentions from which experimental sciences are incorporated into the institutional education of a country.

A starting point, concerning the historical-epistemological approach, is that of the deductivist-constructivist perspective, of a moderate nature, in which these sciences have been developed by collectives of specialists (Hodson, 1985); that their historical development is explainable by assuming the proposal of K. Popper (1962), that of T. S. Kuhn (1972), that of I. Lakatos (1983) or those that work with the category of model. In this line of thought, each theory, paradigm, research program, or scientific model is delimited by a conceptual and methodological language that characterizes it, and each community of specialists has its own norms for admitting proposals that change the schemes within which it has been producing knowledge.

Curricular intentions, which are not independent at all from the historical-epistemological approaches of those who determine them, as well as their political and economic frameworks, are the ones that establish what kind of science is to be socialized and for what purpose this socialization is to be carried out, so they will specify the contents and, to some extent, the educational processes for this task. Such decisions are modified depending on the levels at which the educational system in question is divided.

9.11 The Educational Aspect of Sciences

Although those who produce scientific knowledge cannot be excluded, this problem is the responsibility of science educators. Undoubtedly, these educators are not those who, from a general discourse, talk about the limits and possibilities of pedagogy, but rather they are true specialists in this issue. Even though for analytical purposes it has been separated from the previous one, they form an integrative set of problems with the issue of educability. Therefore, their approach and solution also depend, in a specific way, on the historical-epistemological approach of those who delve into their rigorous study.

The question that directs the problem of the educational aspect of sciences is the one that inquires about this character of them; which means, in relation to each cultural, social, political, and economic context, to specify for what purpose, in the corresponding educational system, sciences, especially at the Basic and Middle education levels, are made the subject of work in the classroom, with a view to the socialization of their historical production and transformation dynamics; also of the changes they introduce in the conception of the world and the relationships between people (STS) and, therefore, are necessarily part of the curricular intentions.

Thus, the problem of the educational aspect of sciences is found in what has already been stipulated about language, the community character, the conception and different action in the world established by theories, paradigms, research programs, or scientific models, different from those of common and everyday knowledge; which are forms of knowledge production that stem from the theories, paradigms, research programs, or scientific models accepted by each community of specialists, with their norms for, as mentioned, admitting innovative proposals that regulate, in turn, belonging. Add to this the special form of reasoning derived from conceptual and methodological structures and the conviction that scientists are not special characters, but are the product of science education and how the educational aspect of sciences has been resolved in the corresponding educational systems.

9.12 The Problem of Educability

Since F. Herbart, it has been posed in terms of the intrinsic property of every human being to be educable or to allow oneself to be educated; it is linked to the assumption that one is moldable by others, as a passive entity. On the other hand, it is also often referred to the biological quality of adaptability. In the present approach and referring to experimental sciences, this tradition is distanced to discuss educability as a pedagogical construction that fosters the critical belonging of new generations to a society affected by the products of scientific and technological research.

Connected as mentioned to education in and the educational aspect of, it is necessary to discriminate it according to the levels and degrees of the educational system, which is why it is analyzed and linked to curricular intentions. It would then be necessary to establish two interrelated classes of membership. The first, which would refer to basic scientific literacy (Fouréz, 1994) to which all citizens are entitled; literacy referred to knowing how to read, write, and speak from the conceptual and methodological languages of the various disciplines, with a view to understanding and consciously participating in that world affected, as mentioned, by the products of scientific research and the ideas they establish about the nature of the world. This literacy must also qualify all members of a nation so that they can participate in decision-making related to scientific and technological development policies. As argued, science and technology cannot continue to be advertised solely in terms of the good they produce for humanity, since they have another side that needs to be revealed, to subject it to citizen control.

At this level of the educational system, educability as a pedagogical construction, and from the relationships between science, technology, and society, must abandon education centered on disciplines, to formulate it from integrating axes of problems, much closer to ordinary people, in the direction of belonging to the current world they have to live in. Educating in disciplines must be a subsequent intention, apart from the fact that pretending that all citizens know chemistry, physics, biology, and others is an absurdity that reveals the state of conceptual and methodological development of science pedagogy, in which those who establish curricular intentions for that level are found.

Secondly, and for higher levels, educability must be formulated holistically with a view to students building positive attitudes towards science, so that they decide in the future to become practitioners of one of them, either in the field of providing a professional service or as knowledge producers, in which case they will become active members of the respective scientific community; this latter will be a task specific to university and postgraduate education.

9.13 A Training Proposal

From a research perspective, the possibility of advancing a new didactical experience is postulated, in the case of the initial training of science teachers, in which the theories or scientific models to be worked on in the classroom are selected, analyzing them from the general and specific historical-epistemological perspectives, using, whenever possible, the original versions. From the didactical point of view, analyze the fields of knowledge that have been related here and, from the pedagogical point of view, education in, the educational aspect of, and the educability that is intended to be promoted with those selected theories or models (Gallego Badillo & Gallego Torres, 2003).

The work with students who begin their training as science teachers must revolve around four main components, with the selected scientific theories or models (ToMc) being the core of the scheme, chosen by the group of specialists who formulate and develop the curricular project. The other three components are the historical-epistemological (H-M), the didactical (D), and the pedagogical (P).

An organization of work in the classroom would begin with the analysis of the internal conceptual and methodological logic of each ToMc object of study; the interactions it accounts for, both explanatorily and descriptively; the questions that what it delimits prohibits; the problems that can be formulated and solved from the structure; and, consequently, the feasible experimental designs. All from the interpretation of the originals in which they were proposed, accepted, and developed. Here, if necessary, the intervention of a team member, responsible for working with students on the mathematization of interactions and the concepts that collect them, would be required. Likewise, a technologist in the design of scientific instruments.

The historical-epistemological (H-E) study of the ToMc would continue, in which the previous ToMc that replaced the one being studied in the classroom would also be clarified, through reading original texts, from the perspective in which that previous one was accepted by the scientific community; what delimited its reference space; from it, what specific problems were formulated and satisfactorily resolved, and that there was at least one problem whose solution was not accepted, which led to the development of the ToMc that replaced it. In accordance with the above, the group of teachers must bring out, identify, characterize, and transform the epistemological conceptions of the students in the initial training program. It would also be necessary to discuss the ideas that the students have developed about what a theory is; what characterizes concepts, methodologies, and scientific models. Likewise, clarify what they understand by definition, postulates (laws), logical demonstrations, and empirical contrasts. All this with reference to the originals of the ToMc.

Based on the results of research published in specialized journals, the epistemological, didactical, and pedagogical conceptions of science teachers would be studied, if possible, in relation to the ToMc being worked on in the classroom. This space must be used for students to analyze the idea they have developed of a science teacher, didactics, and science teaching. The issue of teachability and teaching of that ToMc as didactical problems would then be discussed. This would be in the (D) component of the proposal.

It would then be necessary to relate teaching conceptions with learning conceptions, the so-called E/A relationship, examining those proposed by the group responsible for the training program, based on publications in specialized journals, highlighting epistemological and didactical coherence. The conceptions that students have developed about learning will be brought out and discussed, as well as the relationships they establish with teaching.

The treatment of the aforementioned issues constitutes the space to re-raise the problem of teachability and, as proposed here, the transposition or didactical recontextualization of each ToMc and, consequently, the critical study of teaching texts, including those recommended by the teacher responsible for the study of the internal logic of the respective conceptual and methodological structure. This is the justification for resorting to the originals. The discussion should focus on whether experimental sciences have the structure presented by teaching texts for each of them? Do these structures obey their respective historical developments? What didactical assumptions guide them? Are other organizations possible?

Regarding the pedagogy of sciences (P), in addition to discussing with students the ideas they have about pedagogy from the achieved epistemological transformations, to analyze with them the type of education that would result from the ToMc being studied, its educational aspect, and the type of educability it would promote. The agreements reached would be contrasted with what is intended by the curricular project in which these students are being trained and with what is established by national educational authorities. A rigorous review of the circulating curriculum conception and the so-called curricular theories produced by specialists in this field is also required (Stenhouse, 1991; Hodson, 1988).

Another issue to be studied within the relationship between didactics (D) and pedagogy (P) is evaluation. Working on the usual evaluation conceptions in relation to each ToMc being studied within the initial science teacher training program is to encourage students to analyze those they have developed, their origin, their meaning, their conceptual and methodological foundations, and their consequences. The contrast with the results of research in the field of evaluation published in specialized journals is necessary.

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Chapter 10
The History of Science in Science Teacher Education

Mari A. Lires

10.1 Introduction

Different studies and the personal experience of the author of this chapter in pre-service and in-service teacher training for science education show that a significant percentage of this group develops their teaching activity, or faces it, based on an outdated concept of science, which considers it as a set of truths that have been "discovered" through a single research method, the "scientific method", which is sometimes identified with the inductive and other times with the deductive method (Álvarez-Lires, 1999; Serrallé et al., 2022), without the teachers being aware of its meaning, but always under the umbrella of the supposed objectivity, universality, neutrality and provider of truths of a single science, the Western one.

In addition to the above, despite the growing importance of technoscience in our societies, in recent decades there has been a disinterest among young people in Europe for science studies, and concern for their teaching has increased (Arias Correa, 2012). Examples of this concern have been published, among others, in the following reports: Rocard (2007), ENCIENDE (COSCE, 2011), and Report on Scientific Education (European Commission, 2015). In all of them, three recurring elements are observed in student experiences in science classes, which would shape the initial didactical model for a large part of future teachers, and which could explain this trend towards disinterest in science:

- transmissive, "didactic" model
- decontextualized content
- unnecessary difficulty

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All the cited reports propose a change in traditional methodologies, purely transmissive, and agree on requesting quality scientific teaching that promotes a methodological change capable of truly developing scientific competence (Izquierdo, 2009).

In the same vein, reports such as: Why So Few?: Women in Science, Technology, Engineering, and Mathematics (Hill et al., 2010) have addressed the difficulties of women's access to the technoscientific field, and various research studies have done the same (Álvarez Lires, 2012; Álvarez-Lires et al., 2013).

On the other hand, Izquierdo et al. (Izquierdo et al., 2016) indicate that, in Spain, primary education teacher training includes little experimental science and no history of science (HC). Secondary education teacher training consists of a master's degree, which is taken once a degree in a scientific or technological discipline has been obtained, and includes three credits (15 or 20 h) on the methodology of science (usually includes aspects of HC, but not philosophy of science). In the case of university teachers, training for science education is not contemplated, and the inclusion of HC is non-existent or anecdotal.

It has also been found that some teachers consider the introduction of the history of science (hereinafter, HC) to be a waste of time, in the name of the "efficiency" of dogmatic and axiomatic teaching (Álvarez-Lires, 1998; Serrallé et al., 2022). However, although its introduction will not be the universal panacea that ends the problems of teaching natural sciences, it can be one of the multiple directions in which work is done to reduce the enormous failure observed, produced, among other factors, by that axiomatic orientation.

It is important to take into account, when introducing HC in classrooms, that the teacher's conception of the nature of science (Nature of Science-NOS) will condition the development of their future teaching. According to Clough (2011), NOS refers to questions such as:

- what is and what is not science?
- how does one work in science?
- what are the ontological and epistemological foundations of science?
- how do science and society interact?

NOS, based on its main constituents – the history and philosophy of science – implies a great challenge when trying to introduce it into science teaching (Izquierdo et al., 2016). Initiatives to promote progress in understanding NOS by students have been developed since the last century (McComas et al., 1998), as it is considered a key factor in scientific education (NCR, 2011). Since 1980, studies have been carried out on pedagogical decisions that enable a better understanding of NOS, as a purpose for scientific education in primary, secondary, and university stages; but these investigations reflect that science teachers often do not consider teaching NOS as an important educational objective and even state that this objective is contrary to the purposes of teaching science in educational centers (Abd-el-khalick, 2012; Serrallé, 2018; Serrallé et al., 2022).

If it is admitted that a very important objective of science education is to teach how to think, the history of science, together with an epistemological reflection that allows following the evolution of scientific thought, will surpass the mere transmission of knowledge and promote critical thinking in the classroom (Izquierdo & Sanmartí, 1990). However, we must bear in mind that the objectives of teaching HC must be different depending on the different levels of education or teacher training, and also that new didactical problems may arise when trying to introduce such content.

10.2 The History of Science Today

The history of science is a discipline that has its origins in the eighteenth century, during the Enlightenment, although its antecedents can be traced back to the controversies of the previous century regarding the dichotomy between ancient authors versus modern authors. Since the 1990s, this discipline has aroused increasing interest, so much so that there are numerous international publications on the subject, as well as specialized research (Barona, 1994), along with the celebration of a considerable number of congresses and symposia in which the "convinced group" participates, believing in the utility, interest, and necessity of reflection on scientific-technical work. There are also a set of institutions dedicated to promoting the study and research of the history of science (HC) in Europe and Latin America. However, this research effervescence does not correlate with the implementation of the discipline in curricula or teacher training, domains from which it is practically absent, despite the fact that, as Audigier and Fillon (1991) already pointed out, concern for this implementation dates back to the nineteenth century.

In the context of the reform of the Spanish educational system a few decades ago, the foundations, contents, and methodologies of subjects and the area of natural sciences were reviewed, but, although it is true that the curricular guidelines included the need to consider science-technology-society interactions and to consider science as provisional knowledge, subject to continuous revision and criticism, the issue has remained unresolved, due to the lack of necessary teacher training on the subject, and the published teaching materials do not help much in incorporating HC into teaching; at most, it appears as biographical and hagiographic anecdote. As for university education, the curricula, derived from integration into the European Higher Education Area, have also not addressed the issue, as they have been carried out from traditional disciplines.

10.3 Reasons for This Situation

From what we have said so far, we can deduce that some of the reasons for this situation, which we had already discussed elsewhere (Álvarez-Lires, 1998; Izquierdo et al., 2016), continue to be valid:

- The absence of the history of science in pre-service science teacher education, especially the one conducted in universities and technical schools.
- The lack of attention in secondary education plans and their absence in most university plans.
- The dominant paradigm in educational centers and research: neopositivist, utilitarian, and scientistic.
- The conception of science conveyed by university and secondary education textbooks, as a set of absolute truths, which has emerged ex nihilo thanks to the "scientific method" (it is worth not forgetting that this is the teaching material used, almost exclusively, by a large part of the teaching staff).
- The scarcity of teaching materials.

10.4 What History of Science?

In the event that reference is made to HC in textbooks or teaching materials with a claim to modernity, we almost always find the "history" of some invention, the hagiographic biography of great men, and not women, who have made science, similar to the history of great battles or presenting it as a struggle between light and darkness, between truth and error, in which generous and brilliant knights are armed champions, which has little to do with the reality of its production and construction (Izquierdo et al., 2016). So it would be appropriate to ask ourselves: What history of science?

Burguière (1986) said in this regard:

> It evokes a large number of investigations ranging from the description of an instrument or a machine to the analysis of the conceptual structure of a theory; from the biography of a scientist to the history of a scientific institution, from the influence of philosophical and religious ideas on theories to the quantification of government and industrial grants for research; from statistical epidemiology to the analysis of the social origin of Nobel Prize winners. Like other types of history, the history of science also has uncertain and open borders. It is related to the history of techniques, the history of religious thought, epistemology, and social sciences. From this it follows the existence of a wide range of methods, ranging from philological scholarship applied to the critical edition of a scientific text to an anthropological approach; from statistical methods to the history of institutions (author's translation).

Braunstein (2008) states that HC is not only an erudite discipline, but has been and is at the center of contemporary philosophical debates and has been structured since the 1930s around three main controversies that correspond to different conceptions of science and history: externalism/internalism, continuism/discontinuism; historicism/presentism.

It can be appreciated in what has been said the enormous complexity that is enclosed under the term HC which, on the other hand, is not different from the one that is hidden behind the term science, on which there apparently exists consensus. It is enough to say that the twentieth century has witnessed countless debates and controversies on the subject, which continue in the present century, because "the different perspectives of those who dedicate themselves to the history of science are inextricably linked to the conceptions they have of science itself" (Lacombe, 1997).

10.5 Why and for What Purpose a Teaching of the History of Science

Although, obviously, the objectives of teaching HC must be different if it is aimed at high school or university students, and the same could be said if we are talking about initial or continuing teacher training, we believe that a large part of the purposes that we will expose next can be applicable to it, as long as the necessary specificities are taken into account (Izquierdo et al., 2022). But, before addressing the question of objectives and the didactical interest of such teaching, some of which we have already outlined, it will be convenient for us to pause briefly to think about what the usefulness of HC can be. According to Kragh (1990), they are the following:

- It serves immediately for daily scientific work. It helps to guide research and provides an analytical tool for carrying out a critical evaluation of the concepts and methods of science.
- It is useful for the development of metascientific studies, in relation to the epistemology and sociology of science.
- It has a didactical function about the nature of scientific knowledge, which makes it a discipline capable of exercising a critical and antidogmatic function.
- It can play the role of a link between the two traditionally separated cultures: that of the natural sciences and that of the humanities.
- It does not need, for its existence, pragmatic justifications or connections with other disciplines. It has its own field of action and a status as an autonomous discipline.

We could refer to a multitude of arguments on the subject, which would reflect the different existing visions and which have nourished countless debates, in which we will not enter, but we can affirm that, at present, the historiography of science, overcoming biographical-heroic approaches and even those of the history of ideas, has incorporated approaches from social history and economic history, which have been very productive for studying aspects such as societies, scientific policies, and the institutionalization of science, and for showing that the positivist belief in a neutral science or the dogmatic affirmation of a single scientific method that always brings us closer to the truth were constructions that suffered from a lack of intellectual consistency (Barona, 1994). The aforementioned author indicates that science as a collective construction over time must be the object of analysis. As for the interest of teaching HC, in our opinion, it has a potential: its didactical character, which helps to understand learning problems, while acting on student representations of science, technology, and the relationships between science, technology, gender, and society.

10.6 The Usefulness of the History of Science

The importance of scientific education is undeniable, because science is not only part of humanity's cultural heritage, but also offers a framework of thought that allows us to feel, think, and act to build a more just and sustainable world. Sciences can be a tool for the formation of citizenship (Pujol, 2001), improving their quality of life and their responsible and informed participation (Quintanilla, 2006). Science in school must promote the active participation of students in the world, in addition to promoting a diverse and rich space for dialogue, debate, possibilities for change and restructuring of ideas, as well as the possibility of new ones emerging (Ravanal et al., 2009). Technoscientific progress, moreover, requires that the population understands it in order to intervene appropriately, reflectively, responsibly, and substantiated in decision-making on aspects related to it.

In accordance with various studies, cited in this article, we can affirm that the teaching of HC should aim to question a teaching of natural sciences organized, almost exclusively, around the presentation of results, of already constructed concepts. Thus, it must work on the origin of knowledge, since these respond to problems posed, to questions about phenomena that have been interpreted differently during a long process. Science has not emerged from nothing.

However, in addition, the HC must open a reflection on disciplines and on the intellectual instruments developed to think and explain reality, such as laws, theories, models, or concepts, showing that these have not been constructed cumulatively, but their meaning and use are the product of successive reorganizations. It can and should allow work on the history of ideas, sciences, or techniques, provided that the teaching staff is trained to teach a course capable of simultaneously addressing science, the history of sciences, and epistemology.

Other studies have pointed out the usefulness of teaching HC to detect conceptual obstacles (Piaget & García, 1994) inspired by what is known about historical epistemological obstacles. For their part, Scheidecker and Laporte (1998) indicate that this use must be done with caution, as other different, unforeseen obstacles may arise, because obviously today's circumstances are not the same as those of the historical-scientific period or event studied. In any case, the role that such teaching can play in raising awareness among the student body of the conceptual obstacles that must be overcome, in order to contribute to the reorganization of their thinking through teaching action, is undeniable.

Teaching HC can be a means to reflect on natural sciences as human constructions, showing that scientific theories are historical products that have been questioned, reworked, and subjected to criticism throughout history. It should also point out the importance and interest of debates, controversies, and conflicts of various kinds at play in the production of scientific theories, as well as emphasizing the importance of doubts and errors in advancing scientific knowledge. Error thus takes on another meaning, as it is not only students who make mistakes; great figures in science have experienced it before. This circumstance can help to reinforce students' self-esteem (Fauque, 1998).

In summary, we could say that using HC can allow, among other things:

- To bring out students' representations from, for example, the study of a historical text or the interpretation of an experiment. This will reveal the different representations existing in the classroom. In a second phase, it can be shown that these "spontaneous" representations are insufficient to explain experimental facts, as well as, if they exist, to show the parallelism between such representations and some explanations given at other times by scientific communities.
- To use them to organize future didactical interventions.
- To place the group of students before some historical moments of reorganization of thought.

At the same time, it can offer a vision of how HC has participated in the formation of culture; in addition, any reflection on the relationships between science, technology, gender, and society, on the conditions of production and definition of a science invites us to consider its ethical implications. The scientific and technical production is a social and individual construction that involves values. It is important to ask questions about the meaning of scientific progress, about the role of sciences and techniques in the formation of our societies, about the values involved in the orientations of scientific and technical research (Quintanilla, 2006).

In this way, the teaching of HC contributes to the formation of scientific and technical culture, studying the relationships between science-technology-society and questioning what science is. It will be necessary to analyze at which historical moments the technique has been ahead of science, at which moments it has been the other way around, in which there has been a relative independence between both fields, or how they interact, thus opposing the idea of mechanical and hierarchical dependence between science and technique. It will also be possible to highlight the social influence for both and, consequently, the influence of political, economic, and cultural powers of the time under study, as well as the values involved in the orientation of scientific and technical research.

We must investigate the image that initial teacher training has of science and technique and the insertion of their production in society (Álvarez-Lires & Soneira, 1994; Serrallé et al., 2022). The orientation we are outlining requires reflection on the ethical and cultural assumptions underlying that production and which, almost always, remain hidden. Science is a social, collective, but also personal activity (Fox Keller, 1991; Harding, 1996; Schiebinger, 2014), and those who dedicate themselves to its construction and production are human beings (men and women) who live in relationships within a scientific community and a specific society.

We must highlight the existence of female scientists throughout history (Solsona, 1997; Schiebinger & Klinge, 2013; Álvarez Lires, 2023), but it is also about revaluing those activities that women have traditionally been in charge of and in which they developed extensive knowledge related to the care of diseases, the preparation of food, the washing and bleaching of clothes, dyes, and a long list of other tasks that, although today are in the hands of chemistry, industry, or official medicine, had an existence of many centuries in the everyday knowledge of those who preceded us (Álvarez-Lires et al., 2003). If we achieve the articulation of the objectives set out here, the teaching of HC can be a means of motivating students to study science and reflect on them (García & Izquierdo, 2014). Working on the conditions of knowledge production can contribute to developing more open representations of school disciplines and scientific knowledge.

10.7 Difficulties

We have already pointed out some difficulties when exposing the causes of the absence of such teaching in most curricula or the lack of a habit of teamwork, necessary for multidisciplinary or interdisciplinary approaches, but there are many others of different nature, which we will outline below. We are aware of the difficulty that this teaching entails for most teachers who have not been trained in this field. This situation generates insecurity and rejection, but, in addition, we must add to this the almost absolute lack of appropriate teaching materials at all educational levels.

On the other hand, our naivety is not so great as to make us believe that everything is advantageous when introducing the teaching of HC. There are didactical problems, such as the appearance of new conceptual obstacles, the difficulty of living with doubt and uncertainty, the choice between different historiographic-didactical approaches that exist, and a long list of other issues. Also, we would like to point out a few problems, of a historical-epistemological nature (Álvarez-Lires, 1999), that we have encountered in teaching practice, not to discourage teachers, but in an attempt to address the complexity of the issue:

- The danger of judging scientific productions in the light of current knowledge.
- The implicit assumption of linear and cumulative progress of scientific knowledge.
- The difficulty of the necessary multidisciplinary or interdisciplinary approach.
- The problem of the relationship between reality and the models used to explain it.
- The idea, implicit or explicit, that the scientific method (inductive, deductive?) consists of a set of rules that allow access to truthful knowledge.
- The reinforcement of students' spontaneous representations.
- The use of biographical anecdotes, which can reinforce ideas such as the notion that scientific and technical production is the exclusive work of certain genius men.
- The presentation of current theories in a cause-and-effect relationship with previous ones.

For all these reasons, the choice of study texts or videos and their presentation must be done with great care. On the other hand, we want to emphasize the intellectual enrichment provided by the knowledge of the development of a discipline: A work that delves into its sources allows relating the conceptual framework that has been formed and the problem that is being attempted to solve. This way of working allows understanding different conceptual frameworks from the current ones, used to interpret phenomena that we now understand well and that are explained by current theories (Álvarez-Lires et al., 2013; Libran, 2015). It also allows us to know the relationship between science and the culture (values) of a specific time and analyze the influence of sciences – of a style of conceptualizing – on the development of a society" (Izquierdo & Sanmartí, 1990).

10.8 Use of Historical Texts: Modeling and Evolution of Scientific Ideas

In the context of the Master's program for Secondary Education teachers, we have carried out analyses of original historical-scientific texts to promote training in this field. We have started from the sources, unraveling their implicit meaning, investigating the underlying conceptual framework, in order to understand the corresponding modeling processes (Halbwachs, 1974; Robardet & Guillaud, 1994). The interest in revealing the model lies in making students aware that the object of science is not only to describe phenomena but also to develop thinking and language tools that allow interpreting reality and predicting other different phenomena. In addition, we believe it is important, in order to understand the processes of science construction, to reflect on the validity of the model at a specific moment, based on the coherence between the scientific thought system and the experimental facts it seeks to interpret. The reasons for abandoning the model, the processes of scientific change related to the interpretation of reality in light of new experimental facts or the historical evolution of knowledge, must be investigated, taking into account the social, cultural, and epistemological context (Izquierdo & Merino, 2009; Clemente Gonçalves & Adúriz-Bravo, 2023).

By analyzing a set of properly sequenced texts, it will be possible to verify the existence of different scientific explanations referring to the same phenomena, all of them coherent and rigorously constructed. The validity and conceptual richness of the models can be measured by their ability to produce new experiences in the scientific community of that time. Hélène Metzger (Metzger, 1969, 1974) believes that, when studied in this way, alchemy, iatrochemistry, or other disciplines that are not considered sciences today will not seem like aberrations, but rather fruitful models of a past time that have contributed to the process of production and construction of modern science. The appropriation of a model's structure can be a framework in which scientific-technical knowledge is acquired and can allow observing the progress of science and technology, a process that is not linear, in which differences, reorganizations, and breaks appear throughout history.

On the other hand, studying through texts the different methodologies employed by the "wise" or even by the same person at different times or processes will demystify the idea of a single scientific method for all cases. It will be observed that research can be empiricist, that reasoning by analogy is used, the inductive approach, the hypothetical-deductive, or a mixture of two or more methodologies.

All of this can also allow us to detect epistemological obstacles (Bachelard, 1934). To do this, first, it is necessary to know the historical-epistemological framework of the period under study, within which the author's thought must be placed, what their conceptions are, or what their research program is. It is also advisable to provide some biographical-scientific notes.

Next, as we have indicated, the aim is to investigate the scientific model of the studied process, through the theoretical explanations and the experiences described. Following Halbwachs (1974) and Robardet and Guillaud (1994), we have used a sequence of identification of different aspects, distinguishing between the experimental and theoretical fields, and also conceptual maps.

The sequence used, taken from Scheidecker and Laporte (1998), has been the following:

- Identification of experimental objects.
- Relationships between experimental objects.
- Theoretical objects.
- Relationships between the theoretical and experimental fields.
- The underlying conceptual model.

We emphasize that we have encountered difficulties in separating one aspect from another when analyzing the texts, as it is difficult to escape the interaction that exists between them. In scientific thought, they are surely inseparable. Finally, we want to point out that the use of texts is not the only way to introduce HC, but it is also possible to illustrate this knowledge by carrying out the experiments indicated in them when the information is sufficient, and with the didactical use of museums and old natural history cabinets (Bugallo, 1998; Libran, 2015).

We have also used HC videos within didactical proposals for the study of electricity and the history of the cell and microscopy, in which the evolution of ideas, controversies, errors, and personal motivations are shown, as well as the interaction between science and technology throughout the centuries. The development and conclusions of this experience can be consulted in Álvarez-Lires et al. (Álvarez-Lires et al., 2013).

10.9 Towards the Future

In this chapter, reflections and examples have been outlined that show the usefulness and necessity of including HC in teacher training, but an intervention is needed that moves towards the institutionalization of its teaching and integration into the teaching of experimental sciences, which could be specified in the following.

- Introduction of HC in university and secondary education curricula.
- Promotion of research in this field.

- Establishment of third-cycle university courses related to HC, as well as in the continuous training of teachers, which also include the necessary epistemological reflection.
- Development of texts and teaching materials, which include critical historical views of science.

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Chapter 11
Modeling: A Proposal to Rethink the Science We Teach

Pilar García and Neus Sanmartí

11.1 Introduction

One of the decisions that we science teachers have to make concerns "what scientific knowledge" is important for our students to learn today. Although educational administrations set content and objectives, we teachers have a wide margin of maneuver and, in fact, faced with the same "official" curriculum, there are no two teachers who teach the same thing. We often complain about textbooks, since we teachers tend to base ourselves on them for planning and not so much on ministerial guidelines or on the knowledge that is being generated in the field of science education. And the authors of these books complain about the publishers, since they are often the ones who strongly condition their structure and even their content. But publishers act based on demand, and it has been proven that innovative books sell much less than books with the same content and activities as always. For all these reasons, it can be said that in fact, we teachers are the ones who condition the guidelines adopted by publishers and those who select what to teach and not so much the ministerial curricular proposals. And we can also have a more central role by influencing the change of these proposals, if we consider it convenient, through teacher associations or other platforms.

One of the problems that is generally referred to is the large amount of scientific knowledge to be taught. Textbooks are organized into lessons and these into sections, each of which usually includes at least one important concept. Students tend to perceive these learning proposals as a sum of ideas to be repeated in exams, without recognizing which are the core and important ones, the relationships between them, and even less with the phenomena and facts of the world they explain

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and with the ways in which scientific knowledge has been generated throughout history. Currently, it is agreed that, in addition to learning ideas from science, it is important to learn what is meant by science and the processes associated with the generation of this type of knowledge (Duschl, 2007; OECD, 2006, 2016).

This knowledge increases day by day, and its learning is added to that of always. Now, in addition to learning the concepts of chemical bonding and its different types, students must know what a plastic is and the types of plastics. And in addition to the laws of inheritance, know what cloning or a transgenic organism is. Many textbooks present this new knowledge in separate lessons and sections, and although the experts who have written them know the interrelationships, these are not recognized by the students, since neither the selection of key ideas nor the sequencing of learning activities allows their construction.

In recent years, new "curricula" or content selection proposals have been generated that have focused on identifying a few major ideas of science to be taught and their progression throughout the school years (see, for example, the curricula of Australia[1] and the USA[2]). To characterize these big ideas, they talk about "core" ideas (or central ideas), idea plots (García, 1998), and also theoretical models (Schwarz & White, 2005; Adúriz-Bravo & Izquierdo-Aymerich, 2009). There are many publications that theorize about a model-based curricular vision (Clement & Rea-Ramírez, 2008; Adúriz-Bravo, 2009), and reviews have also been made on the different meanings of the term when applied in school (Oh & Oh, 2011). It is an ongoing field of research in science education, as in many cases only proposals and "progression hypotheses" not yet validated are available. But there is no doubt that it is a challenge in the coming years.

In this chapter, we will base a curricular proposal for science teaching related to the learning of theoretical models and with a selection and sequencing of activities aimed at the construction of these models or modeling. The ideas presented will be exemplified from a work carried out with 15-year-old students about the modeling of the chromosomal theory of inheritance.

11.2 Science: A Type of Culture That Builds Theoretical Models to Explain Phenomena

Science is part of the culture built by men and women over the centuries. In this sense, it is similar to literature, painting, music, or history. The different scientific theories and models are human achievements, and their teaching enables new generations to access this type of knowledge. We could therefore affirm that one purpose of teaching science in school is to help students appropriate this culture, that

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[1] https://www.education.vic.gov.au/school/teachers/teachingresources/discipline/science/continuum/Pages/conceptmaps.aspx

[2] https://www.nap.edu/read/18290/chapter/1

is, to achieve scientific literacy (Holbrook & Rannikmae, 2009). Scientific knowledge is different from everyday knowledge, and to access it, specific learning is required, which, at least currently, is only carried out in school. However, scientific culture should not be equated with mere knowledge of facts and information. For this type of knowledge, school is not needed, especially in the present era, which has ample means to find information quickly. To know the name of the parts of the digestive tube, it is best to propose to the students to search for the information on the Internet, because if they ever do not remember where the pancreas is, they can know how to search for this data. Using class time to "explain" this information is a waste of time that should be used for learning knowledge that enables understanding and, especially, critical analysis, since many unvalidated information can be found on the Internet.

Scientific culture refers to the set of models and theories currently known to answer questions about the phenomena that happen around us. To justify why living beings need nourishment and explain how they do it, it is necessary to have built a systemic model of a living being and relate what we see - for example, that we eat different types of food - with what we do not see - cells. But we also need to have built a model about what this thing we call energy (which we obtain by eating) is and how it can be that food is transformed in our body (chemical change model).

Models and theories are cultural constructs that science has devised to make sense of natural phenomena. They are powerful because they explain many different facts. With the force model, we explain things as diverse as the fall of an apple, the movement of planets, or why the Earth is spherical. But understanding what a force is from the perspective of physics requires the mediation of the school. Few students can appropriate this idea by consulting the Internet or reading a book. Without interacting with an expert person, learners only build "common sense" knowledge, which has nothing to do with scientific knowledge (although it can be useful for solving everyday problems).

However, many current curricula respond little to this purpose of learning science. In very few cases are they oriented to teach thinking through theories and even less, show the questions or problems that triggered significant changes in the ways of explaining phenomena, the social context in which they were raised, or the aspects that favored new answers and the relevant social facts that explain the current moment.

The question we ask ourselves is whether it is possible to teach most students to think theoretically through models and to be able to apply these models to the interpretation of facts without the teachers "explaining" them. Many times, teachers give up on this, as it is easier to get them to memorize information and definitions. But in our experience, we have found that, although it takes time, coordination, perseverance, and facing the challenge with enthusiasm, with good didactical planning by the teachers, it is possible to achieve it.

11.3 Models for School Science

We believe that to become capable of thinking and speaking from science in the analysis of real problems, it is necessary to learn to use theoretical frameworks developed throughout history. Even so, we find opposing views on the nature of scientific theories. From a traditional approach, it is considered that models and theories are true or false depending on whether they fit reality or not, even though no reality fully satisfies these idealized interpretations. On the other hand, from the perspective of considering Science as knowledge based on models, it is accepted that interpretations do not come directly from reality but from models, "abstract objects whose behavior exactly matches the definitions" but whose relationship with the real world is complex. "The model-reality fit is not global, but only relative to those aspects of the world that models try to capture" (Giere, 1999:64). And as Izquierdo et al. (1999) point out, "Theoretical models are (. . .) the main entities of scientific knowledge, as long as they connect with phenomena and allow thinking about them in order to act".

To help understand this point of view, it is useful to analyze, as proposed by Giere himself, some properties of maps, although they are obviously not the same as scientific models. A map refers to a reality, but there is no map that reproduces that reality. The selection of characteristics to represent depends not only on the desire of the mapmaker to be objective and faithful to what is observed but also on other criteria. For example, the criterion that its use is practical for a specific purpose (it must serve to locate populations, identify roads. . .). This does not mean that a map does not provide a good representation of reality, nor that we cannot say that some maps are better than others, but none is a photograph of reality.

For Science Education, this view of science implies focusing school activity on the construction of models or frameworks of ideas by students, models that provide them with a representation and explanation of the characteristics of the facts of the world, useful in their evolutionary moment. These models of school science do not have to be the same as those of expert science, although they must be consistent with it. The important conditions they must meet are, on the one hand, that they are meaningful for the students – that they are useful for explaining – and, on the other hand, that they enable their evolution throughout schooling (and throughout life).

Theoretical models, as strong repositories of analogies and metaphors, serve to know something new from what is already known, to unite two realities that until now were strange. Thinking through models enables establishing relationships between "the real" and "the constructed" and developing a multicausal vision by considering more than one variable at the same time, all with the purpose of being able to predict and explain. Models are, therefore, the main constructs of school scientific knowledge, as long as they connect with phenomena that are relevant to learners and allow them to think about them in order to act (Izquierdo et al., 1999; Justi, 2006; Windschitl et al., 2008; Adúriz-Bravo & Izquierdo-Aymerich, 2009).

11.4 Teaching Science as a Modeling Process

From this perspective of science, learning in school involves helping students build models that are meaningful to them. These models will be relevant as long as they connect with familiar phenomena about which they can think, talk, and act. We call modeling the process of constructing these relationships and understand that it is a key process for learning science since, through it, students learn to "make sense" of the facts of their world using increasingly complex models.

These theoretical models that students build are the result of adjustments between their world experiences and the provisional representations they propose to explain them. As Driver et al. (1994) said, scientific knowledge is of a symbolic nature and socially negotiated, and the objects of science are not the phenomena of nature but the constructs that the scientific community has developed to interpret it. This view implies a radical change in the conception of what is important to teach and how to do it in the field of science. From this point of view, doing science in the classroom involves carrying out an activity in which the analysis of reality (inquiry), modeling, and argumentation intersect to promote a rational reconstruction of phenomena (Jiménez-Aleixandre, 1998; Izquierdo et al., 1999; Caamaño, 2011). Through this network of actions, different aspects of scientific theories are introduced and put into play, which are selected and prioritized by teachers based on their significance, social relevance, and suitability for students.

Learning is not a linear activity but a complex one, the result of many small restructurings in relation to different "nodes" of a network that is being built. There is no single path, but each student finds their own, even though there are key nodes that cannot be overlooked. A student may be able to define many concepts in isolation, but if they have not established relationships based on a model that gives coherence to everything they are learning, this knowledge will not help them interpret the world around them. For example, they may know what a cell is, a chromosome, sexual reproduction, and meiosis, but this does not guarantee that they can relate these concepts to explain how hereditary traits are transferred from one generation to another.

Generally, science is taught in a way that places great importance on students expressing concepts correctly, while not leaving room for creativity, doubt, and divergent thinking, forgetting that these aspects are essential in all scientific activity. That is, the construction of scientific knowledge is not taught, but rather it is given as already constructed. The great theoretical models of science are not learned by repeating what the teacher says or what is written in books or on the Internet. To construct them, it is necessary to start from the analysis of contextualized situations, close to the students' interests and socially relevant, and apply inquiry processes, that is, to start from the analysis of the concrete in order to build the theoretical model – more abstract and general – reflecting on one's own ideas and seeking evidence to validate them. Students have experiences and ideas about the interpretation of these contextualized situations that need to be questioned in order to gradually construct less familiar and more abstract entities – generated within the framework of science – to explain the facts being analyzed and to support the actions that may be derived (Sanmartí & Izquierdo, 1997).

In this sense, it is very important to properly plan the sequence of teaching-learning activities so that, starting from the students' previous experiences and ideas, it promotes the construction of progressively more abstract and complex meanings, that is, modeling processes. Hence, there is currently research around possible progression hypotheses in learning the big ideas of science (Duschl et al., 2011) and how they can be built through inquiry processes. In this regard, it is worth questioning many inquiry practices in which it is assumed that the student will "discover" scientific knowledge from observing phenomena and searching for information on the Internet (Couso, 2014) and, instead, propose them as modeling processes (Windschitl et al., 2008).

Therefore, it will be necessary to design didactical proposals (Acher et al., 2007; Schwarz et al., 2009) that encourage the search for evidence to validate ideas and promote creativity in the development of arguments, so that the theoretical models being constructed are meaningful ("powerful"), make sense to students, and provide them with autonomy when thinking and talking about phenomena.

11.5 Social Relevance of Scientific Learning

If we share the idea that the purpose of school is to prepare individuals to understand, have opinions, and intervene in their community in a responsible, fair, supportive, and democratic way (García, 2002), the teaching of science is a fundamental component of this transformation. Science enables understanding the world, making predictions, and acting in the environment. This is why topics related to Environmental Education, Health Education, and, in general, education in relation to socio-scientific controversies are considered so important. School science must connect with everyday problems and be useful for people to be more autonomous in decision-making and capable of participating democratically in solving society's problems, based on validated knowledge and not on personal opinions or pseudo-scientific arguments (Díaz Moreno & Jiménez-Liso, 2012; Domènech-Casal, 2017).

Currently, science teaching curricula are defined based on the development of competencies. This concept can have very diverse meanings, but one of the definitions states that it is the: "Ability to act effectively in diverse, complex, and unpredictable situations; it relies on knowledge, but also on values, experience. . ." (Eurydice, 2002). This specification emphasizes competence as a capacity related to acting in unpredictable situations (and, therefore, being able to apply new knowledge to decision-making in contexts different from those analyzed throughout the learning process), and complex situations that require interrelating many variables in space and time.

In this line, to become competent, it is necessary for the school to promote the construction of complex theoretical models in students. Knowledge cannot be transferred from having learned only to solve specific problems or to repeat definitions of atomized ideas, but it is necessary to abstract the abstract models that are behind the resolution processes. Only if a good model of force or "living being" has been constructed can very diverse, complex, and unpredictable phenomena be interpreted. And, in addition, it is necessary to appropriate what scientific knowledge implies, how it is generated, and how it evolves. That is, the knowledge that is learned must be meaningful from science and socially relevant.

In the case of scientific learning, the PISA project defined scientific competence in the year 2000 as the "Ability of students to use scientific knowledge to identify questions and draw conclusions from evidence, in order to understand and help make decisions about the natural world and the changes that human activity produces" (OECD, 2001). In this definition, in addition to the aspects mentioned in the definition of general competence, two key aspects of scientific learning are emphasized:

(a) Ability to ask "good" questions. Teachers tend to ask generally very simple questions in which they only intend for students to reproduce what they read in a text or observe, and this is the type of question that students learn to ask. Few times do we teach to propose interesting questions when we all know that, in the genesis of scientific knowledge, questions are a key aspect (Roca, 2005; Roca et al., 2013) and condition the modeling processes (Márquez et al., 2004)
(b) Ability to deduce conclusions based on evidence. The evolution of theoretical models and the increase in their degree of complexity and abstraction is mainly due to recognizing whether the evidence confirms or not the ideas expressed. Generally, the experimentation proposed in the classroom is oriented towards the visualization of given statements and the verification of laws, but much less towards the search for evidence.

The definition of scientific competence within the PISA assessment program has evolved over the years (OECD, 2006, 2016), focusing on the concept of scientific literacy and emphasizing the distinction between "scientific knowledge", "knowledge of the processes of science" and "epistemic knowledge" (how science validates ideas), as well as the distinction between the fields of action: Personal, Local/National, and Global.

The situations in which to make decisions are many, diverse, and unpredictable. The problems of the future are not the current ones, so it is important that the school promotes the learning of transferable theoretical models, that is, big ideas that enable generating arguments in relation to facts not specifically worked on in the classroom. If, for example, work is done within the framework of "projects", the object of learning in the school is not the specific theme of the project, but the knowledge (of all types) that is generated and applicable to new problems that require well-founded participation in personal and social transformation actions (Sanmartí & Márquez, 2017).

11.6 Learning to Speak and Read Science as a Requirement for Learning Sciences

In science classes, students are continually asked to express their ideas orally or in writing, to describe, present points of view, argue them, etc. All this linguistic activity has a dual mediating function in learning: on the one hand, stimulating learners to "shape" what they have heard or read and what they think and, on the other hand, promoting interactive evaluation-regulation by contrasting the different verbalizations and suggesting changes.

Therefore, the verbal expression of ideas enables both their organization and the possibility of discussing and validating them, all of which contributes to the construction of knowledge. Just as scientists refine their ideas by writing articles and evaluating and revising them when presenting them to the scientific community at conferences and publications, students organize and review theirs by communicating them within the framework of school scientific activities (Edwards, 1992; Sanmartí et al., 2002). The language of scientific writings has well-defined characteristics: it is precise, unambiguous, rigorous, formal, impersonal, and often hypothetical (Sutton, 1997). Ideas must be well-founded and organized. It is learned only in school (or in contexts related to scientific knowledge) since it is different from the language used in everyday contexts.

However, learning the language of science should not be confused with learning its specific vocabulary, even though, as some studies have highlighted, more new words can be learned in an hour of Biology class than in another English class of the same course. Rather, as Lemke (1997) pointed out, it is about learning to "speak science", a "language" that serves to communicate in the scientific context. For students to progress in the construction of scientific knowledge, they must come to know both the "thematic pattern" (knowledge) and the "structural pattern" (way of communicating) specific to each discipline, and they must be taught together.

The construction of the scientific model is strongly interrelated with the construction of the vocabulary to express ideas and the use of appropriate discursive forms. For example, burning a peanut in class, the combustion of a candle or gasoline can promote the construction of the "chemical change" model if, in addition to observing relevant facts (function of oxygen, changes in mass, substances, energy…), it is discussed and written about. As students try to express the facts and the model they are building to interpret them, they will need new words and expressions to talk about what they observe and think. Scientific language is characterized not only by its vocabulary and symbolism but also by its linguistic structures. For example, the sky we observe is not described in the same way in a scientific context as in a poetic one, and hypothetical language is essential in scientific discourse. The "thematic pattern" must necessarily be complemented with the learning of this "linguistic pattern", since for a description, explanation, or argument to be meaningful, it is necessary to select the scientifically relevant aspects and express them in a way that communicates thought well (Jiménez-Aleixandre et al., 2009).

At the same time, learning to read critically texts that include science ideas is another significant challenge of scientific learning (Márquez & Prat, 2005). Nowadays, it is easy to access any information through the Internet, but unlike when searching in an encyclopedia written by people with good knowledge of the subjects, the ideas and arguments found on the web are not contrasted. This requires being a critical reader, that is, capable of discerning between validated information and those that only respond to personal opinions, often false (Oliveras & Sanmartí, 2009). To do this, it is necessary to have built theoretical models that enable understanding the various information and deciding on their possible validity, at the same time as other essential reading strategies: who has written the text and what is their degree of knowledge of the subject, for what purpose it is written... (Oliveras et al., 2014).

Although students learn to read and write in language classes, it does not imply that they know how to apply this knowledge when reading and writing in science class, both because scientific language has its own "rules of the game" – its "pattern" – and because the same text can communicate different ideas depending on the meaning given by the person who reads it based on their references. Therefore, the task of science teachers is to help relate linguistic knowledge and scientific knowledge, and it cannot be expected that most students will establish these relationships autonomously, without the help of an expert person.

11.7 An Example of a Modeling Process in the Classroom Learning of Genetics

Is it possible to teach genetics to our students today in a way that is relevant to them and meaningful from a scientific perspective? The first question we asked ourselves in line with what has been said before was what sense it could make for students to learn genetics in the compulsory education stage. Our reflection started from considering that appropriating this cultural knowledge means not only being able to reproduce the scientific information from textbooks or teachers' explanations but also that students come to use this knowledge to think, talk, and act on the world in situations that arise in they daily life. And what can these situations be? How can we recognize that they are socially relevant? To answer these questions, it is necessary to think about the ones that students can ask based on their reality, for example, about the similarities and differences between family members in traits such as eye color, hair type, blood group..., or why children are born with hereditary diseases or congenital anomalies..., or about many of the topics they will find when reading the newspaper or on the Internet: transgenic foods, stem cells, cloning organisms... These and other problems that undoubtedly interest students have little to do with the situations that traditionally appear in school texts, heavily influenced by the academic tradition, in which the study of genetics often begins with Mendel's experiments with pea plants.

The second challenge we faced was how to make students' learning meaningful in relation to current scientific knowledge, as well as socially relevant. However, appropriating this theoretical knowledge is not easy. Scientists, when discussing models, have constructed entities and a symbolic and abstract language. Often, it is assumed that by teaching the so-called "scientific vocabulary," the student already appropriates its meaning and forgets that, if the model is to be used to explain the facts of the world, its construction must be promoted at an individual level, and this involves a complex mental process.

For example, geneticists use letters to represent genes and their alleles. These symbols represent units of information and, therefore, constitute entities with a specific meaning. It is easy to see that students can learn to use these symbols as an algorithm, without appropriating their meaning. Perhaps this is useful for passing the subject, but it is not enough to explain facts from their environment, such as those mentioned earlier. In the case of genetics, we believe that for meaningful learning, it is necessary for students to become capable of using the basic ideas of the chromosomal theory of inheritance. The goal is for students to explain facts they know, such as similarities between relatives and others, using this theoretical model. This implies changing the way they "see" and talk about the facts. For example, in everyday life, it is interpreted that it is the characters themselves – eye color or earlobe shape – that are inherited and transferred, while students will have to learn to "see" and talk about non-visible theoretical entities such as "cells, chromosomes, DNA, genes, meiosis, fertilization..." to explain these same facts. As Ogborn et al. (1998) wrote, a scientific explanation is like an iceberg: we observe a fact (the small visible part of the iceberg) and to explain it, we must talk about multiple ideas that we do not see (the submerged part of the iceberg).

One of the ways of "seeing" and "looking" in science is to search for regularities. If we can get students to explain the transmission of hereditary traits based on the theoretical model mentioned earlier, they will be able to recognize regularities from a wide variety of observations, as the different inheritance patterns –dominance, recessiveness, codominance, sex-linked inheritance– can be interpreted with the same theoretical model: the chromosomal theory of inheritance. Learning to use this model goes beyond knowing Mendel's experiments and laws. Instead, it involves recognizing the relationships between genes and chromosomes, and between these and the different phases of the biological cycle, the formation of reproductive cells, fertilization, and the development of the new individual from the egg cell.

A third aspect that we considered in the didactical design was the need to develop students' ability to describe, explain, justify, and argue scientifically as a condition for learning to speak and write meaningfully about the interpretation of inheritance problems. To do this, they needed to learn to use the language of science, which is more than stating technical words. It involves, as already indicated, learning both the "structural pattern" (textual forms specific to scientific language) and the "thematic pattern" (concepts and theoretical models), as for a description, explanation, or argument to be meaningful and relevant, it requires both selecting scientifically relevant aspects and knowing how to differentiate the required textual forms to adapt to the demand.

Although students learn to read and write in language classes, this does not imply that they know how to apply this knowledge when reading and writing in science class. Therefore, we believe that it is also the task of science teachers to help relate linguistic knowledge and scientific knowledge. The challenge for those of us who teach is to design a didactical process and materials that facilitate students' construction of all this knowledge. This involves making a series of decisions not only in relation to content, that is, what to teach and in what order to do it, but also in how to do it, that is, from what activities and practical situations.

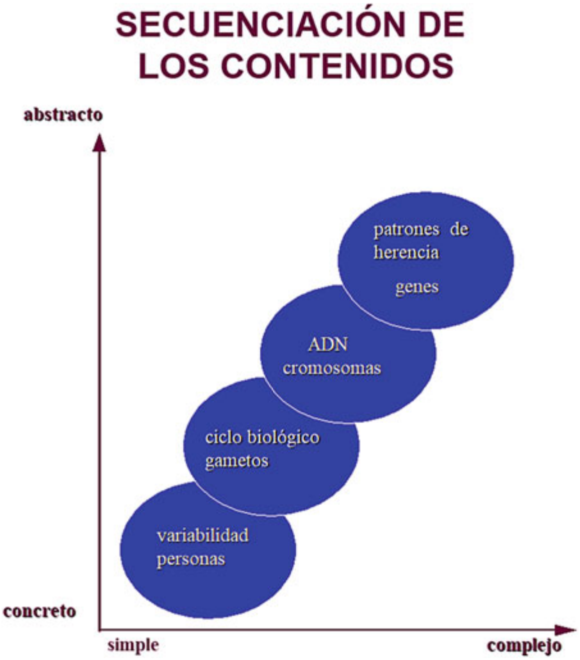
In our case, we designed a didactical unit titled "Similar but different," in which we proposed to our 15-year-old students the analysis of situations and problems of people, to learn the concepts and basic procedures of genetics (based on the chromosomal model of inheritance). The study of human traits is much more interesting and familiar to students than the color and shape of peas. In nature, there are individuals, people or other living beings, with a specific phenotype and genotype that mate with each other and have offspring, and not individuals selected for a specific purpose as in the case of Mendel's experiments. This does not deny the importance of knowing the historical figure of Mendel and his role in the genesis of the knowledge of inheritance mechanisms.

To decide the sequence of teaching-learning, we took into account the students' previous experiences and ideas on the subject. Learning activities were designed to promote a process of constructing progressively more abstract and complex meanings. Doing this requires planning teaching as a process (Fig. 11.1) in which concrete, close, and familiar situations from the students' world are analyzed first, and gradually and progressively less familiar and more abstract entities – generated within the framework of science – are introduced to explain the same facts (Sanmartí & Izquierdo, 1997).

In our case, we started the topic by studying the variability of people in the class for a set of physical traits, traits very familiar to all students, most of which can be observed directly. Students can explain the transmission of some of these traits based on kinship relationships. Next, the function of reproductive cells as a vehicle for this transmission was introduced, relating them to the biological cycle. At that point, the explanations that students had to develop to interpret the similarities and differences between people were at the "organism" level, and the cells – invisible and less familiar – were the entities they had to use to explain. In the next stage, the concept of "chromosome" was introduced as the structure that is preserved, duplicated, and transferred by mitosis to transfer information from the egg cell to all other cells of the body, or by meiosis when forming reproductive cells: eggs or sperm. Explanations were now at the cellular level, and it was necessary to use a new entity, the chromosome – a cell structure – to explain how information is transmitted from one cell to another during the process of cell reproduction.

Subsequently, the entity "DNA" was introduced as one of the chemical substances that make up chromosomes. We considered that, although it is not necessary to talk about the chemical composition of this substance, it is important to recognize the relevant characteristics in relation to its biological function: suitability for storing many different informative messages and for copying them faithfully, but the possibility of random changes essential for understanding how the great variability of living beings has been generated. The concept of gene is introduced as a unit of

Fig. 11.1 Sequencing of content



information located on a specific chromosome. From this point on, students can use the chromosomal theory of inheritance to explain how traits are transmitted from parents to children.

Analyzing this sequencing of content, it can be seen that the level of abstraction required to explain the same fact is increasingly higher – whether it is explained at the organism level, cellular level, or chromosomal and gene level – (see Fig. 11.1). This sequencing favors, on the one hand, the interrelated construction of the concepts involved at different theoretical levels and, on the other hand, the awareness of which facts and aspects are relevant to explain and which depend on the context of each situation.

The activities carried out throughout the learning process were very diverse. They ranged from reflection exercises in which students had to describe, explain, justify, and/or argue using their ideas, to the construction and use of materialized models: chromosomes, DNA fragments to simulate cell division processes, or replication of hereditary material. They also learned to order karyotypes, diagnose from them, and use DNA fingerprints for similar purposes. Problems were solved through computer simulation (Llort & Garcia, 1999) and with pencil and paper, and finally, students conducted surveys of their family on some morphological trait and developed hypotheses about the inheritance pattern or patterns compatible with their data.

Some of the activities were specifically aimed at promoting awareness of the characteristics of the texts they were asked to write, and others at stimulating self-regulation of the model through the construction and use of tools such as guidance bases or evaluation criteria (García & Sanmarti, 1998). These activities were designed to help students learn to anticipate and plan the conditions required for the development of each type of text and to learn to evaluate them with the aim of achieving a high level of quality. The activities were planned so that students would analyze close situations and see the relationship between the model they were building and facts from their environment. In our experience, we found that students became involved in the work largely because they were often the protagonists of the problems posed. For example, the characteristics of the twins analyzed were classmates; the genotype they wanted to know was that of one of the young people in the class and their parents and siblings; each student prepared their family's pedigree for a specific trait and made hypotheses to deduce the inheritance pattern based on the available data; etc.

Finding situations from the students' immediate environment for study is not exceptional. Since the goal of science education is precisely to promote the interpretation of natural phenomena, it is necessary for teachers to recognize which situations can best facilitate the construction of the proposed scientific models, rather than presenting their learning in a decontextualized manner. An example of such an activity would be the one included in the second figure of the annex.

In it, you can see how the student comes to use scientific language in a way similar to how experts do, but first they need to build the necessary knowledge and appropriate its meaning, and this is not easy. We believe that it cannot be assumed that when a student is able to repeat what is written in a textbook, it is an indicator that they have already learned, because ideas are presented in a synthetic and abstract way. Only when the student has individually carried out this process of abstraction and synthesis can the words of the book acquire a meaning close to that given by the teacher. Although sometimes it is assumed that one can learn science by reading the textbook, in reality the process is just the opposite: only when the theoretical model has already been constructed does what is read begin to have meaning for the students.

11.8 Conclusions

Many years ago, Aristotle argued that people become virtuous not so much because they are taught or think sensibly, but because they act virtuously. Following this reasoning, it is important that students become virtuous in using science and technology in their daily lives, and that the design of science courses and evaluation systems are in line with this educational purpose (Powers, 1990). We must ask ourselves if we want to train young people who, in relation to science, are routine, reproductive, unimaginative, or creative individuals with divergent thinking, self-demanding, etc.

This requires a thorough review of what science we want our students to learn, and one of the changes involves focusing teaching on processes that promote the construction of theoretical models that explain many phenomena and enable well-founded arguments on how to act in the face of the facts we experience. These models or networks of ideas, interrelated with the processes that have made it possible to construct them throughout the history of science and which involve speaking in a new language, are very different from repeating “true” and atomized scientific knowledge included in textbooks and evaluating them in exams with many questions that require declarative knowledge, which do not ensure that the learner is able to use the new knowledge to act responsibly.

We believe that we cannot give up on students learning meaningful knowledge, science. This is not incompatible with them being interested and motivated. On the contrary, when boys and girls realize that they are capable of using scientific ideas to explain in meaningful ways, it is precisely when true motivation is generated. Very often we give up from the beginning on students constructing these big ideas because we believe they are too abstract and complex, and most will not be able to appropriate them. But it has been proven that if a team of teachers (it is a collective task and not just one person’s responsibility) aims for learning by seeking suitable paths, the results are good.

An essential condition is to generate challenges, mystery, and for them to perceive that what they are intended to learn is unknown to them and can be interesting and useful. As Ogborn et al. (1998) write, it is necessary to “create differences.” In this line, although sometimes teachers do not perceive it, for students, it is a source of motivation to be able to use the models of science meaningfully to explain problematic situations close to them and of their interest. It is not about science being fun, but about recognizing its usefulness for interpreting various facts and predicting them. As Jorge Wagensberg says in one of his aphorisms, “Intellectual joy through understanding occurs at the exact moment when one discovers that two different things have something in common.”

We should not confuse utility with a specific and immediate application. For example, we could ask ourselves what use it is for students (and ourselves) to know the model of how the Universe is explained. But Astronomy has been a basic knowledge in the history of science and is part of our culture. Just think of the ignorance of the defenders of the “flat earth” theory, which rejects validated scientific knowledge and carries conservative values. Therefore, it is so important that the learning of the theoretical models of science is intertwined with learning about what is “that thing” we call science that involves validating these models based on practicing certain values.

Appendix

Assessment Activity (application of the constructed model). Examples of a student’s answers.

How is the Rh factor inherited?

Remember: The Rh factor is hereditary. The gene responsible for the Rh factor has two alleles D, d. The D allele is responsible for the presence of Rh antigens in blood cells, while the allele determines that these cells do not have Rh antigens. The D allele is dominant over d.

Observe the following figure (first column) and try to deduce why. Think about the information that chromosomes of people from one group or another can carry and represent it in the corresponding place of the figure.

* The last two columns were drawn by the student.

Apply what you have learned:

Fran's father and mother are Rh+. Fran and his sister Iris have the same phenotype as their parents, but their brother Manolo is Rh-.

Represent the phenotypes of all the people in this family in a pedigree.

Could you deduce the genotype, for the Rh factor, of Fran's parents? Explain how you deduced it.

Can you know the genotype of Manolo, Fran, and Iris? Explain it.

Student's answers:

The pedigree of the family is:

To know the genotype of the people in the first generation (the father and the mother) we have to base ourselves on their phenotypes and those of their children. In both cases, the phenotype is Rh+. Therefore, their possible genotypes are DD (homozygous dominant) or Dd (heterozygous). But this couple has had a child who is Rh– (Manolo) who is homozygous recessive (dd). For this reason, we can assure that the genotypes of the parents are Dd, since otherwise, they could never have a child with Rh–.

Manolo's phenotype is Rh– and for this reason, we can assure that his genotype is dd, since, based on the hereditary model where the D allele is the dominant and d the recessive, it is the only possible genotype for this phenotype, it must be homozygous recessive. Fran and Iris are Rh + like their parents. Their possible genotypes are DD (homozygous dominant) or Dd (heterozygous). But in this case, we cannot say which of the two genotypes they have, since we do not have data from a third generation corresponding to their children.

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Chapter 12
Didactics of Science as a Bridge Between Research and Teacher Education: Exploring Approaches to Teaching Chemical Equilibrium

Raquel Katzkowicz and Beatriz Macedo

12.1 Introduction

We present below an update of the original chapter, as we are convinced that the conclusions arising from the research carried out remain valid and propose ideas that could enrich the teacher training program in science in general and in chemistry in particular.

In many Latin American countries, the teaching of natural sciences has very little development or it is very recent. This is an eminently practical discipline that develops, proposes, and experiments with alternative intervention models to improve student learning. We understand that this will only be possible if this discipline is closely linked to the initial and in-service training of science teachers.

The teaching of sciences should be, in the initial training of science teachers, the integrating space between training in the specialty and the epistemological, psychological, and educational science contributions. In turn, the production of knowledge in research on science teaching should respond to the real needs that arise in classroom situations and educational establishments, and their results should have a practical and effective impact on the development of teaching and learning processes, that is, applying them to classroom experiences.

In this context, the research carried out in recent years in this area has provided knowledge that could help teachers reformulate their classroom tasks. Among other aspects, we could mention how research shows how important it would be for teachers to recognize the existence of certain conceptions in their students that can be useful for learning or can become obstacles to it. In the same way, by analyzing

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their own conceptions, the teachers, based on an authentic reflection on their practice, could contribute to improving science teaching in the classroom. Another aspect that should be considered, according to research, from a teaching proposal that analyzes the "why" and "how" to teach science in addition to the "what", would be to take into account that science teaching is aimed at students who, for the most part, will not be scientists, so an emphasis should be placed on teaching science for all citizens, allowing the democratization of its social use, including values related to the STSE (science, technology, society, and environment) relationship, and integrating knowledge related to the quality of life of students and their community. In this context, we understand that, among other aspects, to consolidate the teaching of experimental sciences in the region, it would be necessary to:

- Create spaces for didactical research and training.
- Promote the participation of practicing teachers in these research-training and reflection spaces on their practices.
- Facilitate the exchange between Latin American researcher-trainers, to increase the critical academic community.

For the reasons stated above, from the Scientific Education Program of the UNESCO Regional Office for Education in Latin America and the Caribbean, we have understood that one way to improve the teaching of natural sciences in the region is the creation of spaces for discussion and exchange between teachers and researchers in science teaching, so that teachers are not only actors in the processes of change but also authors of these.

The work we present below takes into account some of the aspects considered and was carried out within the framework of the investigations sponsored by the Regional Office with the aim that their results stimulate teachers' reflection on their daily practices and can thus have an impact on real and well-founded changes in the classroom. It is a contribution from Uruguayan researchers who work on a topic that presents difficulties in teaching chemistry: chemical equilibrium. This research analyzes the strategies proposed by teachers as a means to understand their conceptions about student learning and, on the other hand, the way the topic of chemical equilibrium is approached with the intention of understanding how the difficulties pointed out are addressed. We found it to be an original contribution, as it not only generates a real exchange between in-service teachers, researchers, and teacher trainers (which we have suggested as essential to consolidate the teaching of sciences), but also makes recommendations for initial training, and this is done based on the analysis of the teachers' own reflection on their classroom practice. The researchers also use original research strategies, such as the analysis of teachers' planning, which they complement with interviews and classroom visits.

12.2 Justification of the Topic

According to our experience in teaching chemistry at the secondary level, we know the difficulties that the approach to the topic of chemical equilibrium presents, which lead to obstacles in learning and its subsequent application. Pozo and Gómez Crespo (1998), referring to some difficulties in learning chemistry, say: Understanding chemistry would involve a change in the logic from which the student organizes their theories (epistemological change). The transition from students' first intuitive theories to a scientific view of different problems involves overcoming conceptions organized around what we have called naive realism, with a view of the world centered on its perceptual aspects (things are as we see them), to what we have called constructivism or relativism, characterized by an interpretation of reality based on models. [...] The different concepts and magnitudes used in the description of matter would not exist by themselves, but would be defined and make sense within the framework of a theory. [...] In contrast to the interpretation of changes based on the perceptual aspects of the initial and final states, it is necessary to understand the conservation of non-observable properties of matter and conceive it as a complex system in equilibrium. In particular, regarding the specific difficulties of the chemical equilibrium topic, the same authors state:

> It is easy to see that students who begin to study chemical equilibrium... maintain conceptions in which they interpret that changes in a system affect only one of the processes involved in it, that is, they consider that the system evolves as if there were separate compartments for reactants and products.

In this work, we set out to analyze, on the one hand, the strategies used by teachers as a means of accessing their conceptions about student learning, and on the other hand, the analysis of the approach to the chemical equilibrium topic with the intention of detecting how the difficulties mentioned are addressed.

12.3 Objectives

- Study the possibility of using teachers' planning as an instrument to analyze their conceptions.
- Attempt to detect possible learning difficulties based on the use of teaching procedures that emerge from the study of planning.
- Formulate suggestions to overcome these difficulties in an in-service training proposal.

12.4 Instrument

Following the methodology of research on teacher thinking, we decided to use class planning as an instrument for research. According to Dino Salinas Fernández (1994):

> Teaching planning [. . .] as a work area prior to "teaching", constitutes a privileged space for the assessment and transformation of one's own teaching, that is, for reflection on what, as teachers and given certain working conditions, we want and can do in the classroom; but also for reflection on what we wanted and could not or did not know how to do [. . .]. It turns out that what teachers think, and especially how they think, becomes a fundamental piece of that puzzle that is understanding, explaining, and trying to improve what we call teaching. [. . .] Planning means thinking about "what can be done" and this, to a large extent, is determined by the perceptions that teachers have about "what should be done", and about their own students and the context in which they work.

To test our research instrument, we asked five teachers (who were not part of the population to be investigated) to develop a plan for the first three classes addressing the chemical equilibrium topic. They were not given any instructions, in order to detect which elements they considered when carrying out the requested work. Upon analyzing these proposals, it was found that aspects we considered fundamental to understanding their conceptions about teaching this topic were not present. For this reason, after the test, a relatively open guiding guideline was developed, in which some aspects that we were interested in having the teacher consider were made explicit, which was sent to sixty teachers from Montevideo and the interior of Uruguay.

12.5 Target Population

Planning was requested from teachers who are in charge of the courses in which the chemical equilibrium topic is formally introduced, in the 2nd year of diversified high school, biological and scientific orientation. Knowing that in similar works a relatively low return rate is expected, we asked 60 teachers from all over the country to carry out these plans, in order to obtain the quantities that we had set as our goal. In the end, we have 26 works to analyze from active teachers. These 26 works are broken down as follows:

- Twelve teachers graduated from Teacher Training Institutes with more than ten years of seniority, 2 from the interior (who are teachers of the Teacher Training Institutes of their respective departments, where Primary Education teachers are trained) and ten from Montevideo.
- Three teachers graduated from Teacher Training Institutes, with less than ten years of seniority, all from Montevideo.
- Four teachers not graduated from Teacher Training Institutes with more than ten years of seniority, of which two are from the interior and two from Montevideo.

- Seven teachers not graduated from Teacher Training Institutes with less than ten years of seniority, of which five are from the interior and two from Montevideo.

Likewise, in accordance with the provisions, we have the planning of two teachers from the Artigas Teachers Institute, one in Didactics of Chemistry and another in General Chemistry 2. The study of the works shows a careful and detailed elaboration by the teachers who collaborated in this research.

12.6 Analysis of the Plannings

Our working assumption was that from the study of the plannings we could obtain information about the teachers' conceptions related to the teaching of the chemical equilibrium topic, based on their methodological proposals, as well as the treatment of the conceptual aspects of the topic that can favor or hinder the learning of the students. The plannings were studied using the analysis guidelines proposed in the research project, adapted from a guideline that Coll (1999) proposes for class observation, from which we took those aspects that seemed appropriate for the analysis of the plannings.

12.7 Dimensions Related to Context

12.7.1 Physical Context

In relation to this, we thought it pertinent to take into account aspects related to density (number of students/available space) and the materials with which the class works. The analysis of the plannings revealed that only 3 teachers take into account the density when planning their classes on the chemical equilibrium topic. These are very particular cases, two of which are working in the Adolescents and Adults Plan with labor constraints, which is an experimental plan with face-to-face or semi-face-to-face modality, for overage students who work and attend night schools. The third case corresponds to a teacher who works in Teacher Training Institutes and in technological chemistry high school courses, which has forced him to deeper and more updated reflections on the courses.

We transcribe the reflection of one of these teachers:

> When planning the course, the population density of the groups must be taken into account, as it affects the type and number of activities to be developed. Although this project aims to reduce dropout, in institutions that carry out activities in night schedules, the number of students decreases throughout the year, which allows the use of different strategies, depending on the attending students.

Regarding materials, all the plannings include some material that is distributed in class to support classroom work: exercise handouts, guide texts, videos, etc.

For the semi-face-to-face modality, one teacher indicates that:

> The teacher will provide bibliography, as well as exercises, problematic situations, etc., that can support the student in their own learning path and discover, if any, difficulties and doubts that will be raised in the class.

Regarding experimental activities, all teachers understand that they are fundamental; the courses are structured so that students carry out laboratory practices weekly, which are expected to be strongly coordinated with the theoretical course, but often are not. In the theoretical course, some teachers introduce the chemical equilibrium topic based on a demonstrative experimental activity, which complements those carried out in the practical course.

One teacher points out:

> The experimental activity occupies a very important place, both in the presentation and in the development and resignification of the concepts and procedures worked on. It is about proposing experimental activities in which the student actively participates and elaborates their own conclusions, as well as encouraging practical activity proposals from them, and studying their feasibility in a group.

12.7.2 Temporal Context

It should be noted that in the plannings there is no indication whatsoever in this regard: the location in the annual school calendar, nor the location in the weekly school schedule is not indicated. We must point out that there is a single national program, which, although it has some flexibility, sets thematic sequences that determine approximately at what point in the course the different thematic contents are developed. That is why, perhaps, this dimension does not appear in the analyzed documents.

12.7.3 Institutional Context

This item included the possible distinction between the type of center (public or private, confessional or secular, etc.), as well as the connection of the classroom activity with the existence (or not) of a center educational project.

In general, the reference to the type of center is not explicit, except in the three teachers already mentioned, who strongly contextualize their activity based on the type of center. In none of the plannings is the center educational project mentioned. One of the few teachers who refers to the topic states:

> The planning of the chemical equilibrium topic, like any other, MUST consider the institutional context. It is not the same if it is about students of the technological chemistry high school, strongly motivated, who are going to work as soon as they finish their secondary education in laboratories of different industries, than if they are students of the diversified high school education. The motivation from which the topic begins will also have to be different, and the social context to which the institution belongs and the orientation chosen by the students should be considered to a greater extent.

On the other hand, one of the teachers of the Experimental Night Plan states:

> The students we receive are working teenagers and adults who, in many cases, have family responsibilities. There are two age groups: young people who have been on average two years without studying chemistry, adults who have been on average ten years without studying chemistry. The objective of the plan is to motivate the student to continue studying, reduce dropout rates, without lowering the quality of education.

12.8 Dimensions Related to the Development of the Didactical Activity

Identification and overall characterization of the different parts or segments of the activity.

In all cases, the different parts of the activity are identified, in terms of the organization and sequencing of the conceptual contents to be addressed, as well as the progressive elaboration of concepts through the different segments.

12.8.1 Dimensions for the Analysis of Each of the Parts or Segments of the Activity

Sub-dimensions related to the purpose. Only nine teachers out of 26 define general objectives and objectives for each class, related exclusively to the learning of conceptual contents. In the other 19 cases, there is no mention of the purpose of the planned activity. For example, one teacher states as an objective for the first class:

> At the end of the class, the student must be able to relate the concepts that allow them to deduce the dynamic nature of chemical equilibrium.

Another teacher expresses, in terms of class objectives:

> Recognize and define a system in equilibrium. Differentiate homogeneous and heterogeneous equilibria.

Sub-dimensions related to the content. All, without exception, establish the nature and characteristics of the conceptual contents worked on. Only in seven of those 26 plans are attitudinal and procedural contents also established to be developed. As for the type of tasks proposed, they are generally very structured, with a defined final result, and consist basically of solving algorithmic exercises (not problems), occasionally carrying out a demonstrative experimental activity, and no open activities are proposed.

We find the reflections of one teacher particularly interesting, revealing a different elaboration of the topic:

> It is through problem situations, which are real problems for students, that they learn and construct. Algorithmic exercises are also essential, but they should not be given much class time, but rather use work methodologies that allow students to develop by interacting with each other and thus contemplating diversity. Students present their results and other subgroups act as evaluators of the activity carried out.

It is interesting to note the reflection of a teacher regarding a possible approach that can be linked to a CTSA proposal:

> Biological, industrial, and environmental topics should not be an appendix at the end of the topic on which teachers inform or send to search for material, but rather, from them, problem situations should be posed and through them make students elaborate their concepts and learn the procedural, as well as the topic of values.

Sub-dimensions related to the how. From the plans, it emerges that in general, classes are strongly guided by the teacher, who is the one who sets the work assignment. However, in several cases, there is an attempt to encourage participation and student work in the classroom, and even in some plans, the formation of work groups for solving exercises and problematic situations proposed by the teacher is indicated. In the case of the Experimental Night Plan, spaces are given for students to propose and design activities, and their initiative is encouraged.

A teacher of this plan specifically proposes for the development of a practical activity, the following work modality:

Didactical activities to develop:

- Starting from the students' prior knowledge, working with the pH scale
- Use of the pH meter
- Indicator reagents
- Measurement of pH of commonly used systems, provided by the students
- Measurement of pH of acids of equal concentration and different strength

From the practical, students are given a guided questionnaire, which involves the interpretation of results and the bibliographic search for answers to the questions raised and observations made.

Sub-dimensions related to the expected product and its assessment. Only in ten plans is there mention of student assessment, although the instruments used for this are not indicated. Even in these cases, in general, only summative or final assessment is mentioned. In only one case is the need for course evaluation and possible replanning mentioned, in case this evaluation indicates it.

12.9 Relationships Between the Different Parts or Segments Identified in the Activity

We tried to distinguish within the activity an introduction, the development of the class, and its closure. The way of introducing the topic is varied: some do it through a demonstrative experimental activity, others start the class by revisiting aspects of previously studied topics that can be related to chemical equilibrium, in other cases students are asked to search for material related to the topic. In several cases, the development of the topic is preceded by a review of the content that the teacher considers prerequisites.

In this sense, one teacher states the following:

> An oral survey is conducted. If difficulties arise, a brief review is carried out at the moment the difficulty arises. For the introduction of the chemical equilibrium topic, some prerequisites are the following: physical and chemical phenomena, homogeneous and heterogeneous systems, stoichiometry, amount of substance (mol), ideal gas laws.

In another case, it is indicated:

> Discussion of the prior idea that students bring that physical phenomena are reversible, but chemical phenomena are not.

The most common way to introduce the topic is through the presentation by the teacher of examples of reactions in which equilibrium is reached, and the equilibrium situation is characterized, both macroscopically and from the corpuscular interpretation. Regarding the development of the topic, as we already indicated, the sequence of conceptual contents is well explained in all the analyzed works. Thus, for example, one teacher proposes for the three requested classes:

12.9.1 Sequence of Selected Contents

- Equilibrium state in physical phenomena (review of liquid-vapor equilibrium in a closed system)
- Reversible reactions
- Chemical equilibrium. Characteristics and conditions
- Equilibrium constant as a function of concentrations (Kc)
- Meaning of very high or low Kc values

- Equilibrium constant as a function of partial pressures for equilibria involving gaseous substances (Kp)
- Relationship between Kc and Kp constants
- Homogeneous and heterogeneous equilibria
- Resolution of exercises
- Another teacher indicates, for the first class:

Class development. Etymology of the word equilibrium. Chemical expressions of physical and chemical processes are presented. Homogeneous and heterogeneous systems are identified; reactants and products; types of reaction. The conditions of "reversibility" and properties of the systems under study, macroscopic and others, are deduced. Students are induced to relate reactant and resultant concentration with reaction time in a graph. In all cases, in the initial three classes, the equilibrium constant is introduced, and the variation of system composition is discussed when concentration, pressure, and temperature conditions are modified. Various exercises are proposed and solved on this aspect.

Regarding the closure of the activity of each class, in general, it is not stated how it is carried out.

12.10 Interviews

Once the plans were analyzed, we found that from them we could not draw enough conclusions to configure different categories of conceptions about teaching the equilibrium topic. For this reason, we decided to interview a teacher from each of the indicated groups, trying to clarify aspects that had not been explained in their plans. The interviews were carried out taking into account the analysis guidelines that we used in the study of written documents. In them, the teachers were able to verbalize, with great suitability, those aspects that were not present in their plans.

Regarding the physical context, in the interviews conducted with the teachers, they stated that, although they carry out a basic common planning for all groups, in which they do not consider these elements, they are taken into account when developing the course in each group and in each institution in particular. As for the materials, this topic was not addressed in the interviews as it was sufficiently explained in the plans. Regarding the temporal context, teachers express their attachment to the schedule suggested by the thematic sequence proposed by the program, which is why they did not consider it relevant to include it in the planning.

Regarding the institutional context, in general, there is strong coordination among chemistry teachers from each high school, which is voluntary, and occurs in almost all centers, regardless of a center educational project, which teachers claim to be unaware of. When asked about the "why" of teaching the topic, although it is not mentioned in any of the plans, from the interviews conducted, it is clear that the teachers emphasize that students relate aspects of the chemical equilibrium topic to everyday life situations and the explanation of known phenomena. We did not focus too much on the interviews in the dimensions related to the “what” and “how” since these are explicitly stated in the plans.

Regarding evaluation, which is generally mentioned little in the plans and only referring to summative evaluation, in the interviews conducted, teachers indicated continuous evaluation mechanisms used, as well as, in some cases, the use of self-evaluation. They also explained the characteristics of summative evaluation, in which they try to avoid mechanization in solving the proposed situations, as well as always seeking the theoretical basis in solving them.

12.11 Class Visits

To confirm that the stance presented by teachers in the interviews was effectively manifested in classroom work, we decided to visit some classes. Although, due to the time of year, the topic being addressed was different, the use of appropriate teaching strategies to give meaning and significance to the conceptual, procedural, and attitudinal knowledge worked on in class could be verified, which was not included in the analyzed plans.

12.12 Discussion and Conclusions

According to the above, the plans made by the teachers that make up the universe of our research were insufficient for us to draw conclusions regarding both teachers’ conceptions about teaching and the difficulties presented by the development of the chemical equilibrium topic. The interviews conducted showed us much more conceptual richness than the content of the plans. The class visits served to confirm that in the classroom, the teacher handles a variety of teaching strategies to facilitate the construction of learning; these strategies are not explicitly stated in the plans and are closer to what is expressed in the interviews.

In relation to the above, we did not find significant differences between teachers, neither by their initial training nor by their seniority; the plans are, in most cases, just a linear sequence of the development of conceptual content. We did not find enough information in them to decide whether teachers use strategies that promote the constructive learning of their students. We can think that, even without explicitly stating it in their plans, an approach that approximates a constructivist conception of learning underlies the way of working in the classroom.

Another aspect we want to point out is that the proposals made have a basically homogeneous structure, where the diversity of students’ abilities is not mentioned. This lack is not attributable to chemistry teachers in particular, but to the secondary education system, which, in general terms, does not provide mechanisms for detecting diversity, and especially for addressing it.

Regarding individual processes of meaning construction and collective processes of activity construction, although there is no diagnosis on individual capacities, there are some references, in some plans and especially in the interviews, to an adaptation to the characteristics of the group, and consequently to the use of different strategies. Although times are very tight, there are spaces for a certain flexibility that allows addressing the particularities of each group.

One teacher states:

> The annual planning is continuously adjusted, depending on the characteristics of the groups, the number of classes lost due to holidays, strikes, public holidays, etc.

In another of the plans, it is expressed:

> Planning is handled with some flexibility. It is not considered something static and immovable, but it is constantly reviewed and adjusted based on the results obtained and the problems that may arise.

As for the types of content worked on, in general, the conceptual ones are exhaustively described, but other types are hardly mentioned. In the interviews and in the visited classes, however, a concern was observed to promote the development of attitudes and procedural content, but these are not adequately prioritized or made explicit by the teachers.

In few cases, references to the prerequisites necessary to address the chemical equilibrium topic are included, according to what was previously expressed. Given that in the letter sent to the teachers, they were specifically asked about this topic, all of them stated that they consider it important, but they do not naturally include it; it is not part of their class proposal. For a proposal that aims for meaningful learning, it would be essential to take into account the initial state of the students, in order to establish the appropriate strategies to anchor the new content to be learned.

In general, there is no reference to how the passage from the phenomenological to the corpuscular interpretation of observed facts is handled, and vice versa. This aspect constitutes a difficulty for the student, as the interpretation requires a theoretical framework, mainly the use of atomic models, which are often not incorporated by students as a model, but as a reality.

Only one teacher refers to this aspect, stating:

> It is essential to separate the phenomenological from the interpretative and modeling aspects. Various examples are first studied from a phenomenological point of view, making a macroscopic description, recognizing the equilibrium situations. Then, the interpretation of the phenomena is carried out using models. It is necessary to emphasize the speculative nature of models and theories, as well as to overcome the empiricist and inductivist vision that students and many teachers (although we do not declare it) have about the acquisition of knowledge. Teachers must teach modeling skills and encourage students to use multiple models.

Regarding the attribution of meaning and functionality of the learning carried out by students, it should be noted that, except for some particular cases, the introduction of the topic does not establish relationships with phenomena that the student may know from their daily experience or from the study of other subjects. As for the applicability of the acquired knowledge, it is not possible to draw conclusions, since only the introduction of the topic was requested. There are no elements to know how the development of the topic would culminate, nor its eventual applications. As for the evaluation of students, it has already been indicated that, in the few planning instances where it is mentioned, only the final evaluation is referred to, not the diagnostic evaluation or continuous evaluation. This would seem to suggest that evaluation is considered external to the learning process and divorced from it.

As conclusions, we can indicate that in relation to the proposed objectives:

The planning carried out by the chemistry teachers who made up this research population is not an instrument that accurately reflects their classroom work.

From the preceding analysis, we could establish that some ways to explain how students can overcome the difficulties they face in studying this topic could be the following:

Work more emphatically in class on the passage from the phenomenological to the corpuscular.

Take into account the different capacities of young people, to make a proposal that addresses this diversity.

Formalize a didactical proposal that explicates the procedures for solving problematic situations in the student's future, both in the academic area (such as other topics in the second and third year of Diversified High School, eventually at university), and in their future as a rational being, reflective citizen, capable of responsible environmental care.

Explicitly work with students on procedures that require formal reflection, leading them to seek rational explanations for the phenomena surrounding them, banishing magical explanations.

From the above considerations, those aspects that should be included in teacher training programs naturally arise. On the other hand, we believe it is essential that each teacher continually reflects on their own practice, which will lead to improved results in their interaction with students.

Annotated Bibliography

Del Carmen, L. (coord.). (1997). Teaching and learning of Natural Sciences in Secondary Education. ICE of the University of Barcelona/Horsori. Barcelona. This book brings together works by different authors that analyze in depth some aspects related to the problems of teaching and learning natural sciences in Secondary Education.

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teaching is highlighted. The article concludes by presenting the situation of the didactics of natural sciences in Latin America and the Caribbean.

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Nieda, J. and Macedo, B. (1997). A scientific curriculum for students aged 11–14. OEI/UNESCO. The authors carry out an analysis of the contributions that come from different curricular sources and are necessary to consider when deciding what science to teach, why to teach it, and how to teach it. A detailed commentary is presented on the most relevant contributions from psychology, didactics, epistemology, and the social source. Likewise, the authors present possible alternatives in the selection and sequencing of content and methodological orientations that include not only how to teach but also how to evaluate.

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