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Towards a Characterisation of Science Teachers' Pedagogical Content Knowledge of Scientific Explanation. An Exploratory Multiple Case Study.

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DECLARATION

This dissertation is submitted for the degree of Doctor of Philosophy.

I hereby declare that:

i) This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except where specifically indicated in the text and bibliography.

ii) My dissertation is not substantially the same as any that I have submitted, or is being concurrently submitted for a degree or diploma or other qualification at the University of Cambridge or any other University or similar institution. I further state that no substantial part of my dissertation has already been submitted, or is being concurrently submitted for any such degree, diploma or other qualification at the University of Cambridge or any other University of similar institution.

iii) My dissertation does not exceed the limit for the relevant Degree Committee. The length of my dissertation is 79948 words.

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Elisa Izquierdo-Acebes

ABSTRACT

Within the last decades, there has been an increasing interest in the creation of learning environments that emphasise science practices as a means to achieve scientific literacy. This thesis targets one practice: the construction of explanations. To successfully integrate this practice into their classroom, teachers need a particular body of knowledge known as Pedagogical Content Knowledge (PCK). There are virtually no existing studies whose goal is to conceptualise teachers' PCK of scientific explanation. To address this gap, I embarked in a research project driven by the following questions: (Q1a) What ideas, knowledge, and beliefs do teachers hold about scientific explanation?; (Q1b) In what instructional practices do science teachers engage during science lessons to support students in constructing scientific explanations?; (Q1c) How do teachers assess students' attempts to construct explanations?; and (Q2) What do teachers perceive to be the fostering and/or hindering conditions for the teaching of scientific explanation construction in the classroom? I designed a multi-participant exploratory case study approach to solving these questions. Five science teachers from three Secondary schools in Spain and England volunteered to participate. Main data sources included audio-recorded lessons, semi-structured interviews and fieldnotes. Data analysis occurred in multiple steps, being informed by thematic and constant comparative techniques. First, each case was examined separately. Findings from this analysis were presented in the form of participants' case profiles. In a second stage, a cross-case analysis was conducted to identify common patterns among the cases. This allowed for the development of five key assertions: (1) Teachers display a multiplicity of meanings for 'explanation'; (2) Despite being identified as an essential scientific practice, explanation construction –as I have operationalised it– is rarely purposely integrated into instruction; (3) Teachers rarely display specific instructional sequences to promote the construction of scientific explanations. However, they use some strategies to interact and guide students in explanatory episodes; (4) Teachers do not possess specific assessment models for the construction of explanations; and (5) Teachers identified some inhibitors for designing environments in which explanation-production plays a significant role, including large-size classes, crowded syllabi, and a lack of resources and experience. The participants also noted some fostering conditions, including teachers' confidence, autonomy, and support from the school's management team, other teachers, and parents. These findings were discussed in terms of their implications for teacher preparation, research, and practice. Finally, some potential limitations were identified.

A mis padres, que me mostraron el camino del conocimiento;

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TABLE OF CONTENTS

VOLUME I

LIST OF FIGURES

Each figure is labelled according to the Chapter it appears in (e.g., Chapter 3: Figure 3), section (e.g., Section 7: Figure 3.7), subsection (e.g., subsection 2: Figure 3.7.2), and ordinal position (e.g., a: Figure 3.7.2.a).

LIST OF TABLES

Tables are labelled following the same criteria established for the figures.

LIST OF ABBREVIATIONS

Abbreviations are listed in alphabetical order.

§3.4.	Section 3.4.
A.2.	Appendix #2
B.Sc	Bachelor of Science
CER	Claim-Evidence-Reasoning Model of argumentation
D-N	Deductive-Nomological Model of explanation
D-S	Deductive-Statistical explanations
E#ij-Pa	Explanatory Episode number ij, Participant (e.g., E#3-Be: Episode #3, Becca; E#11-Al: Episode #11, Alba)
E-FN	Elisa's Fieldnote(s) – the author.
En.	English
ERP	Educational Research Paradigm
ESO	Educación Secundaria Obligatoria (compulsory secondary education in Spain)
Et al.	And others (et alia)
Fr.	French
I-Ad	Interview with Adrian
I-Al	Interview with Alba
I-Ba	Interview with Barney
I-Be	Interview with Becca
I-Ch	Interview with Christian
Ii-Pa	Informal Interview with Participant
IRF	Initiation-Response-Feedback sequence
I-S	Inductive-Statistical explanations
KAs	Knowledge of Assessment
KIS	Knowledge of Instructional Strategies and representations
KS3, KS4	Key Stage 3, Key Stage 4 (stages of compulsory secondary education in the UK)

KSC	Knowledge of Science Curriculum
KSU	Knowledge of Students' Understanding of Science
LOGSE	Law of General Organisation of the Educational System (1990)
LOMCE	Law for the Improvement of Educational Quality (2015, Spanish current Education law)
MOE	Ministry of Education (Singapore)
NOS	Nature of Science
NRC	National Research Council (US)
OECD	Organisation for Economic Co-operation and Development
OTS	Orientation towards Science and science teaching
PCK	Pedagogical Content Knowledge
PGCE	Postgraduate Certificate in Education (UK)
POE	Predict-Observe-Explain sequence
PRO	Premise-Reasoning-Outcome strategy
PTDR	Phenomenon-Theory-Data-Reasoning Model of scientific explanation
QTS	Qualified Teacher Status (professional qualification for teachers in the UK)
Q1	Research Question #1
Q1a	Research Question #1, sub-question a
SMK	Subject-matter Knowledge
Sp.	Spanish
W-Ba	Workshop about Argumentation with Barney
Yi.Oj-Pa	Year i, Observation number j, Participant (e.g., Y9.O19-Ad: Year 9, Observation #19, Adrian; Y10.O3-Ch: Year 10, Observation #3, Christian)

CHAPTER 1. INTRODUCTION

1.1. Why does the Sun not fall from the sky? The origins of my research

When I was an undergraduate student in Physics, I worked as a babysitter for three siblings on Saturday nights. María, the youngest one, was only three years old when I was hired. Every time I stayed with the children, after watching a movie, I read María a bedtime story. Just before entering the land of slumber, she used to launch some surprising questions. One night, with a serious face, María asked me why the Sun does not fall from the sky. I was amazed by such a deep question in such a small girl; but what surprised me the most was that I did not know what answer to give, which was minimally accurate but could satisfy the desire to understand that inspired her question. As always, María fell sound asleep in a few seconds, but I kept thinking about that question for a while.

During the six years I spent teaching Physics to pre-service technicians in Radiotherapy and Medical Imaging, I had to deal with similar seeking-why questions about natural phenomena, which brought María's anecdote to my mind several times. From my students' questions, I learnt the relevant role that explanations play in science education at different levels. I also realised that explanations may come in many different forms and can be used for a huge variety of purposes. My problem was –again– that on many occasions, I was not sure about the answer I should provide to my students; how much information should I give for the explanation to be satisfactory? Was it better a more complex but less understandable explanation? What kind of language should I use to build the explanation? What did I expect to achieve when explaining something? What could I do to encourage and help my students to construct *their own* explanations?

I found an answer to some of these and other questions when I was studying my degree in Philosophy. In a series of lectures about Hempel's *Philosophy of Natural Science* (Hempel, 1966), I was introduced to many well-renowned philosophers who had consecrated much of their academic life to puzzle out what an explanation is, what differentiates scientific explanations from other explanations, and what makes a scientific explanation a good explanation. After seven decades of reflection and debate, these issues have not yet been entirely settled, but the intellectual advancement during these years has been remarkable.

The interest of philosophers of science in explanation comes from the idea, supported by most, that generating explanatory accounts of phenomena may "render the world more intelligible, comprehensible, and predictable" (Hodson, 1992, p.541) and, therefore, must be a core practice of science. If this is accepted, we can understand why so many researchers and curriculum designers have turned their attention towards scientific explanation in recent years (Braaten & Windschitl 2011; Millar & Osborne 1998; NRC, 2013; OECD, 2019).

When I started designing my PhD research project, I knew I wanted to investigate something related to the introduction of epistemic practices in the science classroom, but I needed to narrow this broad aim down. My supervisor recommended me to read about argumentation in science (both from the curricular and the scholar perspective), since this is one of the most widely studied disciplinary practices. Something that caught my attention was that, in many academic papers, the notion of 'argumentation' was conflated with that of 'explanation' (e.g., Sandoval, 2003; Erduran *et al.,* 2004; McNeill & Krajcik, 2006; Berland & Reiser, 2009; Ruiz-Primo *et al.*, 2010). My background in Philosophy of Science made me aware of the different treatment that philosophers had made of both practices, so I was shocked that such a distinction was not clearly set forth in the field of Science Education.

As for policy documents (e.g., Spanish science National Curriculum), I was bewildered to find only a few lines indicating that students' production of scientific explanations should be encouraged in the classroom. But there were no specifications on what counts as a (good) scientific explanation, what strategies are more effective to teach students how to construct explanations, or how to assess the quality of the explanations produced. That is; as far as I knew, philosophers and other scholars had been discussing scientific explanation for more than 70 years and had not yet agreed on a consensual definition and quality criteria for this practice. However, teachers were supposed to know what to do and how to do it with just a few general sentences. These reflections led me to set out the general objective of my research, which referred to how science teachers interpret and put into practice the requirement of promoting the construction scientific explanations by students in their classrooms.

1.2. Rationale of the study and research questions

One of the major paradigm shifts in philosophy of science concerned the move away from viewing scientific disciplines as collections of pieces of factual knowledge toward conceptualising them as sets of practices (Knorr-Cetina, 1981; Pickering, 1993), being these defined as "the learnable and valued dimensions of disciplinary work, both tacit and explicit, that people develop over time in a specific place" (Stroupe, 2015, p.1034). The movement from science-as-knowledge to science-as-practice culminated in the 1990s, and had a strong impact on the science education realm (Scanlon *et al.*, 2003). Warren and Rosebery (1995) acknowledged, that, "(f)rom this perspective, learning in science cannot be reduced simply to the assimilation of scientific 'facts', the mastery of scientific 'process' skills, the refinement of a mental model, or the correction of misconceptions. Rather, learning in science is conceptualized as the appropriation of a particular way of making sense of the world" (Warren & Rosebery, 1995, p.12). Duschl, Schweingruber, and Shouse (2007) go further into this conceptualisation, developing a connection between scientific practices as a learning goal and as a pedagogical approach.

Although not without difficulties (Lehrer & Schauble, 2006; García-Carmona, 2020), the so-called 'practice turn' (Soler *et al.,* 2014) slowly permeated the science curricula in different countries and, eventually, in teaching practice (Kelly & Licona, 2018; Duschl *et al.,* 2007). This implies that teachers, besides promoting the acquisition of concepts, must create opportunities for students to become legitimate participants in the social and epistemic dimensions of science (Christodoulou & Osborne 2014; Stroupe, 2014). Only by finding the balance between these different dimensions can be ensured that students achieve scientific literacy (Duschl, 2008; DeBoer, 2000). As I will show in this dissertation, this requirement is not exempt from challenges for teachers (Berland *et al.,* 2016; Kang *et al.,* 2014; Osborne *et al.,* 2004).

Among all the practices in which scientists engage, the ones that have received the most attention by scholars are the thus-termed 'epistemic practices.' These are defined as activities (both physical and mental) that lead to the production, justification, evaluation, and refinement of knowledge according to particular rules which are agreed by a community of practitioners (Chang, 2011; Kelly & Licona, 2018). The elaboration of scientific explanations is recognised as one of the core epistemic practices in which students should acquire proficiency (Windschitl *et al.,* 2018). It contributes to strengthening their content knowledge (Braaten & Windschitl 2011; Richmond *et al.,* 2016) and gaining insight into the Nature of Science and the epistemic activities of scientists (Sandoval & Reiser, 2004).

The relevance of scientific explanations for the attainment of scientific literacy has been recognised by policymakers and stakeholders in recent years (McCain, 2015; Tang, 2016). For instance, in the PISA Science Framework it is stated that "(t)o understand and engage in critical discussion about issues that involve science (…) requires three domain-specific competencies. The first is the ability to provide explanatory accounts of natural phenomena" (OECD, 2017, p.98). Similarly, the Next Generation Science Standards establishes that "students are expected to engage in argumentation from evidence; construct explanations; obtain, synthesize, evaluate, and communicate information" (NRC, 2013, p.27). Being able to build explanations is seen, then, as a crucial component of students' scientific education.

Both as a student and a science teacher, I have always deemed the development of explanations a complex practice that entails great cognitive effort. Researchers in education back this belief up (Berland & Reiser, 2009; Braaten & Windschitl, 2011), and claim that the complexity of explanation construction demands it to be explicitly taught (McCain, 2015; McNeill & Krajcik, 2006; Yao *et al.*, 2016) and continually reinforced (Taber, 2013; Tang, 2016). To create and maintain learning environments that nurture explanation production, science teachers must own a range of appropriate design, instructional, and assessment strategies; this, in turn, calls for a specific type of knowledge that Shulman (1986) baptised as Pedagogical Content Knowledge (PCK).

Identified by Shulman as a unique form of professional knowledge for teachers, PCK was an object of discussion since its appearance because of the ambiguity with which it was defined (Kirschner *et al.*, 2015; Lederman & Gess-Newsome, 1992). Consequently, it underwent numerous modifications over the years. Magnusson, Krajcik, and Borko (1999) build upon the work of Shulman (1986, 1987), Grossman (1990), and Tamir (1988) to conceptualise PCK as consisting of five components: Teacher's Orientation towards Science (OTS); Knowledge of Students' Understanding of Science (KSU); Knowledge of Instructional Strategies (KIS); Knowledge of Assessment (KAs); and Knowledge of Science Curriculum (KSC). The so-called Pentagon model of PCK (Park & Chen, 2012; Magnusson *et al.,* 1999) is the one that constitutes the theoretical basis of this dissertation.

Three decades ago, Horwood posed a question to which later researchers gave an affirmative answer: "[i]s it possible that science teachers have a role to play in helping pupils develop explanatory ability –this latter as distinct from being able to recite the explanations of others?" (Horwood, 1988, p. 43). The subsequent question to be asked is 'what do teachers need to know to accomplish this task efficiently?'. To this, there is no definite answer. There are virtually no existing examples of studies whose goal is to characterise the knowledge, beliefs, and skills that encourage or hinder teachers from engaging their students in the construction of scientific explanations.

To address this gap in the academic literature, my research study portrays the PCK of scientific explanation of five secondary Science teachers from three different schools in two different countries, as well as its impact on the design and implementation of explanation-driven learning experiences. More specifically, I focused on (i) teachers' *knowledge and beliefs* about scientific explanation (*Q1a*); (ii) teachers' enacted *instructional practices* to support students in constructing scientific explanations (*Q1b*); (iii) teachers' *assessment expectations and models* for students-made explanations (*Q1c*); and iv) teachers' *perceived fostering and/or hindering* *conditions* for teaching how to produce scientific explanations (*Q2*). Having an understanding of teachers' PCK of scientific explanation may be crucial to assess their needs and to develop supportive professional development and educational experiences about how to effectively teach such a complex and fundamental epistemic practice.

1.3. Structure of the thesis

My dissertation is divided into six chapters. This first chapter provides an overview of the study, including its origins, rationale, research questions, and potential significance. In Chapter 2, the conceptual framework for the study is presented. The objectives of this thesis suggested several research areas that might act as organising frameworks to make sense of two concepts: Scientific Explanation (within the broader notion of 'epistemic practice') and Pedagogical Content Knowledge. Given the number of works related to these *foci* of interest, it is beyond the scope of Chapter 2 to provide an exhaustive and complete review on each of them. Rather, the literature review presented is based on relevance to my research objectives.

Chapter 3 outlines the methodological approach used to conduct the investigation. This includes a description of the research paradigm (qualitative-interpretive), the research methodology (exploratory multiple case study), the data sources (audio-recorded observations and interviews), and the data analysis strategies (thematic and constant comparative analysis). The analytical process occurred in multiple steps. Each case was first analysed separately. I began by developing a coding scheme that was informed by current research on PCK, scientific explanation, and dialogic approaches to teaching. After the initial coding, I wrote a summary profile for each participant to describe their knowledge and beliefs about scientific explanation in science classrooms, their orientations towards the teaching-learning process, their instructional strategies to engage students in explanation building, and their assessment tools and models for this practice. The results of this stage of analysis are reported in Chapter 4 as individual case profiles, each of which includes a discussion of the findings relative to the current academic literature.

In the second phase of analysis, I conducted a cross-case comparison of the five participants, examining the data set for patterns and themes to emerge. Through an iterative process of coding, displaying, and checking, I developed five assertions, which are presented and discussed in Chapter 5. These are: i) Teachers display a multiplicity of meanings for 'explanation'; ii) Despite being identified as an essential science practice, explanation construction –as I have operationalised it– is rarely purposely integrated into instruction; iii) Teachers rarely display specific instructional sequences to promote the formulation of scientific explanations. However, they use some strategies to interact with and guide students in explanatory episodes; iv) Teachers do not possess specific assessment models for the construction of explanations; and v) Teachers' perceive some inhibitors and some fostering conditions for designing explanation-based environments.

Chapter 6 is the final chapter. This chapter includes a summary of the findings and discussions provided in previous chapters, linking them to my research questions and to the relevant academic literature in the field. Potential limitations of the study –which could restrict the generalisability and trustworthiness of the results– are also identified and discussed. I conclude my thesis suggesting some implications for practice and recommendations for future research.

CHAPTER 2. LITERATURE REVIEW

2.1. Overview

In this chapter, I discuss the relevant existing literature on the matters addressed in my research questions (§1.2). Accomplishing such a review plays a significant role in two ways. First, it may help to settle the conceptual framework for the selected problem. In developing this conceptual framework, the reported literature must not be seen as an authority to be blindly obeyed, but as "a useful but fallible source of ideas about what's going on" (Maxwell, 2005, p.35). Secondly, the literature review must justify the need to study the research problem and to suggest potential lines of thought.

Each section of this chapter offers one of the theoretical trends that informed this research. Section 2.2 justifies the need for a study like this. From the notion of 'scientific literacy', I introduce the idea –which will be developed in depth in Section 2.3– that science education should not only focus on the acquisition of conceptual content, but to also accommodate other elements, aimed at producing and applying that content. Section 2.3 is fundamental to understand how science is conceptualised throughout this thesis. I analyse the influence that science studies have had on the educational community to justify the turn towards a science-as-practice education. In Section 2.4, attention is turned to literature on scientific argumentation; this is one of the core science practices that has aroused greater interest among researchers in science education. Studies on argumentation may be a valuable frame of reference towards which to aspire for a different practice: the construction of scientific explanations. In Section 2.5, I summarise what has been said about this epistemic practice from different areas, including philosophy of science, education research, and policy documents. I also examine the differences between explanation and argumentation, trying to justify why these differences are relevant to the science classroom. Based on this review, I propose a model to operationalise scientific explanation for my investigation. Finally, in Section 2.6, I present the notion of Pedagogical Content Knowledge (PCK), with special emphasis on works that have focused on teachers' PCK of science practices.

2.2. Scientific literacy

Among researchers and educators, it is widely accepted that the major purpose of science teachers must be to prepare the broadest number of students (not only those specialising in sciences) to achieve a certain level in their scientific understanding and their ability to use science after formal education (Beyer & Davis, 2008; McNeill & Krajcik, 2006; Osborne, 2007). This educational goal is discussed in the academic literature under the label 'scientific literacy'. Many scholars have highlighted not only the difficulty of promoting scientific literacy among students, but the complexity of accurately defining the term itself (Burbules & Linn, 1991; DeBoer, 2000). Hodson (1992) portrayed scientific literacy as a multidimensional construct founded on three major elements: i) learning science –that is, acquiring conceptual and theoretical knowledge produced by scientists; ii) learning *about* science –developing an understanding about the nature and methods of scientific disciplines, and an awareness of the interactions between science and society; and iii) learning *to do* science –engaging in those activities that lead to the production, refinement and articulation of scientific knowledge (Hodson, 1992; Ohlsson, 1992)[1]. Cavagnetto (2010) defines scientific literacy as an amalgam of "scientific concepts and processes, metacognitive processes, cultural aspects of science and critical reasoning skills" (p.337); these abilities, when taken collectively, replicate science in practice, he says.

For Burbules and Linn (1991), achieving scientific literacy is the consequence of students' preparation for a multiplicity of roles, responsibilities, and epistemological attitudes. To accomplish this arduous task, science teachers need to change the way they teach, moving from strategies based on positivist assumptions to approaches based on inquiry and dialogue. These approaches would help students to participate in the construction of their understanding of the world and would provide a more realistic idea about the scientific enterprise. Burbules and Linn do not specify how to prepare teachers for this change, though. Within the last few decades, many other scholars have made their proposals on how to create learning environments that focus on students' enculturation into the practices of the scientific community –that is, the 'learning to do science' component (Hodson, 1992)– as a pathway to enhance scientific literacy (Jiménez-Aleixandre & Erduran, 2007; Beyer & Davis, 2008; McNeill & Krajcik, 2008; Duschl, 2008; Berland & Reiser, 2009; Aydeniz & Ozdilek, 2015; Brigandt, 2016).

The characterisation and promotion of scientific literacy has been a major focus of interest for stakeholders and policy makers all over the world (McCain, 2015; Tang, 2016). Current curricula and standards also stress the idea that being scientifically literate means more

[1] Although I think that the discussion and analysis developed throughout this chapter will clarify this point, I would like to mention here that the 'learning-to-do' component that Hodson (1992) incorporates to scientific literacy should not be conflated with a mere hands-on or activity-based instruction (Tamir 1988), or with the process skills linked with the scientific method (Ayers & Ayers, 2007). It refers to the disciplinary practices through which scientists (and students) construct and refine knowledge, and these practices cannot be formalised into a perfectly defined and quasi-mechanical method (Kirschner, 1992). Some of the already explored practices in which students should engage include scientific argumentation (Erduran *et al.*, 2004; Duschl, *et al.*, 2007; Berland & McNeill, 2010; McNeill & Krajcik, 2012), modelling (Kelly, 2008), and mechanistic reasoning for prediction and explanation (Russ *et al.* 2008).

than possessing some science content; it is necessary to be competent in the application of that knowledge into situations that emulate the scientists' endeavours. For the Programme for International Student Assessment (OECD, 2013, p.5), the disciplinary practices in which students should achieve proficiency are i) explaining phenomena scientifically; ii) evaluating and designing scientific enquiry; and iii) interpreting data and evidence scientifically. Similarly, the American National Research Council (Duschl *et al.*, 2007, p.36) recognises that those students who are proficient in science: i) can use and interpret scientific explanations of the natural world; ii) are able to generate and evaluate scientific explanations; iii) understand the nature and development of scientific knowledge; and iv) participate productively in scientific practices and discourse.

While elaborating this review about scientific literacy, I could not help wondering where the interest in educational goals that go beyond the acquisition of scientific content arises from. More concretely, I was interested in the origins of the contemporary current that advocates full participation of students in authentic scientific practices (Peker & Dolan, 2014; Sampson *et al.,* 2011). In the next section, I delve into an answer to this question.

2.3. From 'Science-as-knowledge' to 'Science-as-practice'

There is a robust relationship between the way science is taught and the way science is conceptualised; the curriculum, learning objectives, pedagogical strategies, and assessment procedures used in the classroom carry many assumptions about what science is and how it works (Hodson, 1986). Because of this, students' understanding about both the Nature of Science (NOS) and the scientific enterprise, and their attitudes towards science, are strongly influenced by their curricular experiences (Matthews, 1994). For decades, it has been known that the most influential factors in informing and shaping students' attitudes and understanding of what science is are teaching style (Evans & Baker, 1977) and teachers' image of science (Jungwirth, 1971), even if this is not explicitly revealed. The public image of science, as depicted through informal learning channels, can have a perceptible effect too (Lucas, 1983).

If we want students to have an accurate picture of what science is and how it works, we must, then, know about i) what image teachers project in their classrooms, and ii) how science is conceptualised by experts. Regarding the first question, several authors argue that teachers tend to misrepresent the NOS and scientific knowledge in their teaching, since their conceptualisations do not agree with the commonly accepted image of science (Benson, 1989; Hashweh, 1996). Nadeau and Désautels (1984) analysed some assumptions teachers hold about science, concluding that these contribute to the dispersal of five myths: 'naive realism', 'blissful empiricism', 'credulous experimentation', 'excessive rationalism' and 'blind idealism'. These myths, they say, are internalised by teachers during their education and training, and are propagated through the curriculum. Other authors agree that it is common to find teachers (both at secondary and primary schools) who hold positivist and simplistic notions of science, both general (Faikhamta, 2013) and discipline-specific (Lemberger *et al.,* 1999). Aguirre, Haggerty, and Linder (1990) reported that prospective secondary science teachers adhere to positivist views of science. The authors propose that this adherence might be connected with teachers' tendency to embrace transmissive teaching approaches. Likewise, Abell and Smith (1994) accounted for the realist and positivist perspectives hold by pre-service elementary teachers. Conclusions from the investigation conducted by Murcia and Schibeci (1999) with prospective primary teachers are consistent with the previous studies.

Throughout the years, a great number of scholars from many disciplines have tried to elucidate what science is and what scientists do. Philosophers are among those who have devoted the most intellectual effort to solve these questions. Although, in a broad sense, I could go back in my narration until the times of the ancient Greek philosophers, the story begins to get more interesting from the 1930s. By that time, and until the mid-1960s, the prevalent current in philosophy of science was the so-called Logical Positivism. A group of thinkers in Vienna and Berlin –among which Carnap, Hempel, Nagel and Reichenbach stood out– set the intellectual basis for this current. For these philosophers, the only type of legitimate (and reliable) knowledge is scientific knowledge, which can be reduced to a set of symbolic formulae by a process of logical analysis. Logical positivists defended that objectivity in knowledge comes from observation. That is, theories and laws are confirmed by the collection of empirical evidence and evaluated by some formal criteria. Science, then, progresses through a process of accumulation. Over the years, this philosophical current –one of the most influential in the twentieth century, whose legacy is still visible– came to be known as 'the Received View' (Putnam, 1962).

Despite its dominance in the philosophical panorama for decades, internal weakness and external criticism were eroding the foundations of logical positivism, leading to its –slow yet inevitable– collapse. Although numerous philosophers questioned its fundamental assumptions –e.g., Toulmin and Hanson– the author considered the key turning point to break with the Received View is Thomas Kuhn. This physicist and historian of science was not interested in analysing the logical structure of scientific theories and how these are confirmed, but in actual scientific reasoning and the historical structure of scientific change.

In line with these interests, in his writings, Kuhn highlighted the fact that science is performed by a community of practitioners who engage in specific, value-dominated, and consensually agreed disciplinary practices (Kuhn, 1962). Kuhn's ideas, together with contributions from members of other fields (e.g., sociologists of science like Latour and Woolgar) laid the foundations to create what has been called 'social epistemology of science' (Fuller, 1987, 1996; Longino, 2018). According to this epistemology, scientific practices are socially and culturally embedded within a community of people who construct and refine knowledge collectively (Knorr-Cetina, 1981; Lynch, 1993).

Social epistemology can be located in a broader body of scholarship labelled as 'science studies.' Science studies began to take a clear shape in the 1970s, based on ideas coming from history, philosophy, anthropology, and sociology of science, as well as cognitive psychology, computer science, and science education (Duschl, 2008). Scholars within this interdisciplinary research area characterise science as a complex activity that involves much more than experiments and logical inferences; the break with logical positivism –viewed as too idealised and disconnected from how science is performed in real settings– is evident. The focus of interest is moved towards the practices and discourses of scientific communities, which are analysed in detail along multiple dimensions (Soler *et al.*, 2014). This change of focus from propositions to activities (Chang, 2011) set the basis for understanding science as a set of practices instead of merely a body of knowledge. Therefore, researchers within this tradition are considered responsible for was has been denominated the 'practice turn' (Pickering, 1993; Schatzki *et al.,* 2001).

The descriptions of science produced in the tradition of science studies research suggest that scientists engage in many different forms of practice that, taken together, comprise a situated way of knowing (Meyer & Crawford, 2011). To understand the implications this may have for educational settings, it is crucial to examine what is meant by 'practice'. Ankeny *et al*. (2011) define practices as sequences of "organized or regulated activities aimed at the achievement of certain goals" (p.304). Scientific practices are those performed within particular contexts, which require networks of participants and institutions (Fujimura & Latour, 1989) and specialised ways of talking, writing, and reasoning (Bazerman, 1981; Christodoulou & Osborne, 2014); without them, these practices makes no sense (Moura & Guerra, 2016).

Among the large ensemble of activities that are part of the daily routine of the scientists, the ones of interest here are the so-called 'epistemic practices.' Epistemic or knowledge-generative practices are defined by Chang (2011, p.209) as "a coherent set of mental or physical actions (or operations) that are intended to contribute to the production or improvement of knowledge in a particular way, in accordance with some discernible rules (though the rules may be unarticulated)". Another definition is given by Kelly and Licona (2018), according to which "epistemic practices are the socially organized and interactionally accomplished ways that members of a group propose, justify, evaluate, and legitimize knowledge claims" (p.144). For Kitcher (1993), within a research field there should be a consensus about different aspects of epistemic practices, including the language used, the assumptions accepted, and some methodological commitments and assessments procedures, because all these aspects will shape the work of present and future generations of scientists. Epistemic practices are, then, a special kind of disciplinary practices. An example of discipline-based epistemic practice is the elaboration of scientific explanations (Duschl, 2019).

The practice turn, which culminated towards the 1990s, completely changed how science is conceptualised by experts. If descriptions of science that emerge from these studies are legitimate, the impact over the science education community might – and even, should– be considerable, in terms of curriculum, educational aims, instruction, and resources (Scanlon *et al.,* 2003). In 1970, Elkana (p.15) wrote: "it is well known that there is a strong interaction between the philosophy of science and the science of each generation. It is less often stated clearly that there is also an interaction between these two and the teaching of science in so far as it is the philosophy of science which moulds the general attitudes which form the foundations of the various theories of science teaching". Therefore, "we should aim at grounding our theories of science teaching in that philosophy of science which at present seems to us the most advanced" (Elkana, 1970, p.17). One year after, Scheffler (1971) suggested that some debates and problems from 'philosophies-of' that arise "*from scientific practice itself"* (p.62) might contribute to enriching teachers' identities, by acting as triggers for reflection on the foundations of their subjects. Some authors warn, however, that this relationship should not be taken too far, since "(i)t is naïve to assume that a theory of education can be extracted directly from a philosophy of science. These two phenomena belong to different domains; albeit overlapping domains in some aspect" (Swift, 1982, p.39).

These statements are more substantial than they might seem at first glance, because they propose a response to the highly debated question of 'who should define science for the science education community' (Good & Shymansky, 2001). This question is far from trivial if one considers that the image of science perpetuated by some scientists and teachers –in positivistic, realist terms– does not coincide with that promulgated from philosophers of science, sociologists, and science education researchers. So intense was the dispute about how to conceptualise science for the school context, that throughout the decade of the 1990s, some academics came to speak of a 'science war' (Good & Shymansky, 2001). If I position myself on Scheffler and Elkana's side, considering their recommendations in a broad sense, I will say that science studies should be the informing framework for how to teach science. Kutrovátz and Zemplén (2014) seem to agree with this position when they claim that "it is hard to imagine a satisfactory didactic toolkit that neglects the social studies of science" (p.119).

The consideration of this framework has given rise to a proliferation of documents –in the form of reports and recommendations– that advocate the introduction of science practices, in general, and epistemic practices, in particular, in the classroom (Stroupe, 2015). These documents have been elaborated by both national and transnational organisations, and have been widely used to design instructional materials and inform assessments (Braaten & Windschitl, 2011). In *Beyond 2000: Science education for the future*, Millar and Osborne (1998) argue that practice-based learning environments are difficult to create, given that in educational contexts there is an over-emphasis on content, and therefore, all the relevant aspects necessary to grasp science as practice –such as epistemic and social dimensions of science– are seldom present in instruction. The Nuffield Foundation continues on the same line in its *Science Education in Europe: Critical Reflections* report (Osborne & Dillon, 2008), in which some European researchers and educators insist that the primary goal of science education should be to educate students both about the major explanations of the world that science offers and about the way science functions. Curriculum, they say, should facilitate an education about science's achievements and practices to all students. PISA's Draft Science Framework (OECD, 2013) places as one of science education goals helping students to become scientifically literate citizens, making clear that this requires not only knowledge about scientific content, but also about scientific practices and how they enable science to advance.

This shift in focus has permeated the national curricula in many countries. For example, the science syllabus in Singapore (MOE, 2012), where students' learning expectations around participation in science practices are framed. The conceptualisation of the science present in the American Framework for K-12 Science Education seems to draw from the same corpus, since it states that "science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge" (NRC, 2012, p.26) and that those students who are proficient in science are able to "participate productively in scientific practices and discourse" (NRC, 2012, p.36).

To achieve the goal of scientific literacy, then, students must be given opportunities to fully immerse in authentic epistemic activities (Ozcelik & McDonald, 2013). Beyond the general lines sketched in the aforementioned education policy documents, there are many academic papers (Jiménez-Aleixandre & Erduran, 2007; Beyer & Davis, 2008; McNeill & Krajcik, 2008; Duschl, 2008; Berland & Reiser, 2009; Reiser *et al.,* 2012; Aydeniz & Ozdilek, 2015; Stroupe, 2015) that provide hints and recommendations for teachers about how to create learning environments that focus on students' enculturation into the practices of the scientific community.

In a highly influential paper, Duschl (2008) proposes that every scientific practice is integrated by three domains: conceptual, epistemic and social (Figure 2.3). To ensure that learners engage in legitimate and meaningful participation in science-as-practice, teachers must find the balance –the harmony, in Duschl's terms– between these three dimensions. He considers these dimensions as sets of educational goals, which requires working concurrently with curriculum, instruction, and assessment models.

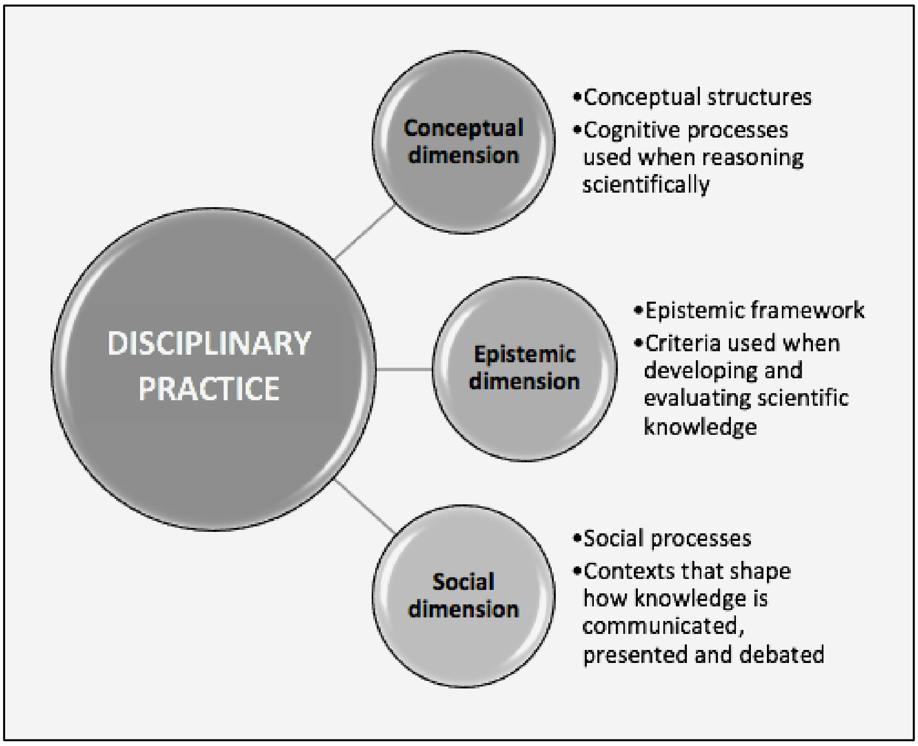

Figure 2.3. The three dimensions of science practices (adopted from Duschl, 2008)

The conceptual aspects of disciplinary practices refer to how conceptual structures (e.g., theories and models) and cognitive processes (e.g., language and memory) are used by agents (Sampson *et al*., 2011). Until now, teachers have centred, almost exclusively, on conceptual goals of science learning. As I have argued, this is changing, albeit very slowly, and the new conceptualisation of science present in curricula and reform documents is opening the door to the creation of environments that also focus on the epistemic aspects of science as learning goals. This second dimension comprises the epistemic frameworks used when developing and evaluating scientific knowledge. This implies that students should be encouraged to reflect on what counts as knowledge, and how the scientific community refines, tests, and evaluates this knowledge before its acceptance (Reiser *et al.,* 2012). All these epistemic activities are governed by norms and values, which constrain what counts as a proper instantiation of the practice (Chang, 2014). Under this approach, normativity goes hand in hand with sociality (Longino, 2018).

Chinn and his team (Chinn, Buckland, & Samarapungavan, 2011; Chinn, Rinehart, & Buckland, 2014; Chinn & Rinehart, 2016) propose a model –the 'AIR' model– that gathers the components that a cognitive agent should consider to fully cover the epistemic dimensions of a disciplinary practice; these components are i) epistemic Aims and values; ii) epistemic Ideals; and iii) Reliable epistemic processes. 'Epistemic Aims' refer to goals related to the development of a representation of how the world is, such as constructing scientific explanations or models, while 'values' refers to the relevance the individual (or the community) concede to these goals. Epistemic ideals include criteria/standards that are used to evaluate whether epistemic aims have been achieved. For example, degree of relevance, correctness, depth, and completeness may be criteria to evaluate explanations (Achinstein, 1971). Epistemic ideals can be used to evaluate the resulting epistemic products. Finally, Reliable epistemic processes include procedures that are likely to result in successful achievement of the defined epistemic Aims. Thus, according to the AIR model, evaluation criteria and strategies in conjunction guarantee achieving epistemic aims. Barzilai and Eilam (2018) found that the explicit instruction of these criteria and strategies have a positive impact on students' performance.

The inclusion of epistemic goals in the learning experience has a fundamental consequence regarding role assignments in the classroom: the student can no longer be considered "a passive receiver of facts or an algorithmic processor of propositions" (Chang, 2011, p.211), but a full-fledged cognitive agent who performs epistemic activities (Stroupe, 2014). That is, students must take, or share, the responsibility for configuring the norms for the distinct practices within the classroom community (Pickering, 1993; Scardamalia & Bereiter, 2006; Tollefsen, 2004). Seeing students as epistemic agents implies considering their desires, beliefs, and expectations, as well as their purposes, capabilities, and resources, as factors in the learning process.

It is possible to find documents in which explicit reference is made to both the epistemic and conceptual aspects of scientific practices (Millar & Osborne, 1998; NRC, 2012). But as Duschl (2008) notes, when engaging in disciplinary practices, these two dimensions cannot be separated from the social processes and contexts that frame how scientific knowledge is developed, refined, communicated, debated, represented, and applied (Dagher & Erduran, 2016). The social nature of scientific practices has long been recognised by a multitude of scholars in very diverse areas. Thereby, if teachers aspire for the classroom to reflect the science cultural and social institutions, learners should be organised as knowledge-producing communities (McGinn & Roth, 2003).

In recent years, the consideration of the social nature of scientific practices has been subject of analysis for researchers in science education from different perspectives. Much of the produced work comes from studies on NOS. One of the points on which academics find consensus is that the production and validation of scientific knowledge is a collaborative and cooperative activity that requires shared norms (Osborne *et al.*, 2003). Abd-El-Khalick (2012) claims, notwithstanding, that most students and teachers display a low appreciation for the social nature of epistemic practices. Beyond asserting that disciplinary authority in science is social, Kelly and Licona (2018) draw on science studies and works on scientific education to argue that the social dimension of scientific practices can, in turn, unfold in various facets. They say all disciplinary practices are interactional (constructed collectively through agreed actions and operations), contextual (situated in social and cultural practices), intertextual (communicated through a particular discourse, which includes shared symbols and rules), and consequential (they have consequences for what counts as legitimate knowledge). These four dimensions should be reflected somehow in the science classroom.

The widely discussed emphasis from researchers and curricula designers on 'science-as-it-is-practised' (Osborne & Dillon, 2008), and their calling for engaging students in authentic disciplinary practices in science classrooms (Lehrer & Schauble, 2006), poses a number of challenges for teachers. It demands to design, guide and scaffold both the instruction of scientific practices and the assessment of learners' abilities to take up the integration of the conceptual, social, and epistemic dimensions of disciplinary work (Kang *et al.,* 2014; Sandoval, 2003; Stroupe, 2015).

Edelson and Reiser (2006) recognise that, although each practice may present its particular challenges, there are some commonalities across practices, that include both pedagogical and practical challenges. Within the first group, the authors cite two: i) helping students deal with the complexity and multidimensionality of authentic practices, and ii) helping students grasp the rationale behind these practices. With respect to the problems with practical implementation, Edelson and Reiser say that iii) teachers have limited time and resources to promote learning activities that engage students in authentic practices; and iv) teachers may have never before incorporated such disciplinary practices into their instruction –usually confined to what Schwab and Brandwein (1962) called the 'rhetoric of conclusions', or the 'final form science' in Duschl's (1990) terms. Moreover, teachers may not have experienced these practices first-hand. Since practice-based teaching requires a previous metacognitive reflection by the teacher (García-Carmona & Acevedo-Díaz, 2018), the lack of training could be a real impediment to incorporate disciplinary practices into the classroom. Within the 'practical challenges' category, I include the challenges derived from the redefinition of the role of students as epistemic agents and not as passive information recipients, since this is opposed to conservative contexts in which the science teacher is positioned as the sole epistemic authority in the classroom (Stroupe, 2015).

In this section, I have presented the shift away from teaching science as a body of established knowledge towards experiencing science as a series of practices for generating, validating, and applying such knowledge. This is one of the most significant changes in science education of the past quarter century (Hodson, 1992). It implies that, in addition to learning concepts, theories, and methods, students should become legitimate participants in the social and epistemic dimensions of science (Duschl, 2008; Stroupe, 2015), in order to develop those repertoires of epistemic practices that are relevant for the scientific community. This 'practice turn' in education reflects the idea that what scientists do and how they do it is just as important as the knowledge they produce. Researchers have designed and studied instructional programmes that focus on distinct discipline-based epistemic practices, including scientific argumentation and scientific investigations (Duschl *et al.*, 2007). In the following section, I analyse the first of these practices.

2.4. The epistemic practice of argumentation

Within the last few decades, science education literature has shown an increasing interest in disciplinary practices that enable learners' engagement with the particulars of the scientific enterprise (Berland & Reiser, 2009; Beyer & Davis, 2008). Among such practices, we find scientific argumentation, which is considered a core epistemic activity of scientific communities (Duschl & Grandy, 2008).

Jiménez-Aleixandre and Erduran (2007) hold that the introduction of argumentation in science learning environments may contribute to i) promote students' access to cognitive and metacognitive reasoning; ii) the development of communication and critical thinking skills; iii) the development of scientific literacy; iv) engagement in practices of scientific culture and the development of epistemic criteria to evaluate knowledge; and v) the growth of reasoning. The benefits of this practice are, therefore, so many and so relevant in the path towards scientific literacy, that it is not surprising that argumentation in formal science education had become a notable focus of research (Osborne & Patterson, 2011).

Several studies have been devoted to examining teachers' difficulties to create a classroom culture in which students can engage in argumentative practices (Kuhn, 2010; Simon, 2008). Newton, Driver, and Osborne (1999) designed a schedule to measure the time spent on this practice in secondary science lessons. They found that classroom discourse was mostly teacher-dominated and tended not to foster a reflective discussion of scientific issues. In order to clarify the reasons why discussions were such a minor feature of students' experience, they conducted some interviews with experienced teachers. Two major reasons were given by the participants: the limitations in their pedagogical repertoires, and the pressure they felt over on account of the National Curriculum and its assessment system.

Kuhn (2010) states that, since argumentation is a core epistemic practice of science, it should be one main goal for science education. However, because the epistemic components of the argumentation cannot be transmitted to students directly, this educational goal turns out to be difficult for teachers. Duschl and Osborne (2002) add that many teachers find it challenging to design argumentative-driven learning environments because they have been encultured in an authoritarian manner that cannot avoid replicating. The authors suggest that to be able to engage their students in argumentative practices, teachers must be provided with theoretical guidance, pedagogical strategies, and resources. Duschl and Osborne mention two different ways to achieve this aim: using the Toulmin's framework (to which I refer shortly) and reflecting on the logic of arguments. They do not opt for either of these options, just pointing to some paths for further research to assist teachers in these tasks (Duschl & Osborne, 2002). A series of theory-driven initiatives involving teacher professional development undertaken by Osborne, Erduran, and Simon sought to give a solution to this problem. The research reported by those scholars in two articles (Osborne *et al*., 2004; Simon *et al.*, 2006) concludes that the overall argumentation skills in students may be significantly improved with the proper intervention on teachers' instruction.

Another researcher interested in studying how to nurture teaching science as argumentation is McNeill. Like Osborne and collaborators, in McNeill's works (McNeill, 2011; McNeill & Krajcik, 2006, 2008) argumentation is modelled by using Toulmin's analytical approach. For Toulmin (1958), the purpose of the argumentation process is to establish the relative merits of a claim. His proposed argument structure comprises the claim, evidence (data) that second or contradict the claim, and the principles (warrants) and assumptions (backing) on which they are based. According to Simon (2008), Toulmin-based materials are beneficial in assisting teachers to conceptualise argumentation and to develop supporting resources for students.

Although Toulmin's framework is an excellent approach to model argumentation in educational settings, some problems may arise if its use is extended, without any changes or further reflection, to the analysis of scientific explanations. This is a –in my view, wrong– step that McNeill, as other scholars (e.g., Ruiz-Primo *et al.,* 2010) takes. She combines the goals of both practices in one that she calls 'scientific explanation' (McNeill & Krajcik, 2006). Other researchers, such as Berland and Reiser (2009), are less clear in their distinction between explanation and argumentation, simply declaring that they are complementary practices. In section 2.5.4, I present a review of other works in which they investigate some demarcation criteria between explanation and argumentation in science, to justify my belief in the need to separate these two practices in the classroom.

2.5. The epistemic practice of Scientific Explanation

Like argumentation, the construction of scientific explanations is viewed by numerous researchers, educators, and curricula designers as one substantial epistemic practice in which students should achieve proficiency (Millar & Osborne, 1998; Berland & Reiser, 2009; Braaten & Windschitl, 2011; NRC, 2012; OECD, 2013; Richmond *et al.,* 2016; de Andrade *et al.,* 2019). This is not surprising if –as many people subscribe– finding explanations of natural phenomena is the ultimate aim of science (Taber, 2007; Yao *et al.,* 2016). One of the answers that philosophers of science have given to the fundamental question 'why do science?' is that scientific knowledge allows us to make predictions, and those predictions can inform interventions in our environment. While this idea that science enables technology is acceptable, most philosophers agree that it does not capture the whole story. A more complete answer is that scientists aim to produce explanations which may help us, in some way, intellectually understand the world (Friedman 1974). As such, it should be integrated and supported in the science classroom.

Some potential benefits of asking students to provide explanations for natural phenomena include: i) it can strengthen conceptual understanding of science (Driver *et al., 2*000; McNeill & Krajcik, 2006), by challenging students to "evaluate, integrate, and elaborate on their knowledge in important ways" (Songer *et al.*, 2012, p.321). Moreover, since explaining requires the mobilisation of diverse conceptual resources and their integration into coherent frameworks (Millar, 2006), there exists certain reciprocity between competence in this practice and the understanding of science content. Thus, student-built explanations can evidence deep learning of core scientific ideas and concepts (Sevian & Gonsalves, 2008) and, at the same time, can help students to delve into their scientific understanding (Beyer & Davis, 2008; Colombo, 2017); ii) it can help students develop the skills needed to effectively engage in scientific practices, through their involvement in the reasoning and discourses of the discipline and their participation in social interaction systems (Beyer & Davis, 2008; Aydeniz & Ozdilek, 2015). This, in turn, could modify their image of science (Bell & Linn, 2000); iii) it can help students develop their epistemological beliefs about scientific knowledge (Kuhn *et al.,* 2006), since for building an explanation they must use and reflect on the standards for what count as a legitimate explanation (Sandoval & Reiser, 2004); and iv) it can contribute to increasing the value learners give to science, so fostering their interest and engagement in the science classroom. Some students may have the feeling that science has nothing to do with their day to day life and their real world, which may lead them to deem science as something senseless and even useless (Lombardi & Oblinger, 2007). One of the reasons that, according to Hodson (1992), contributes to this perception of science is that teachers seldom state explicitly that conceptual structures such as theories and models are produced with the aim of explaining the world. Students, then, must form their views on the role and status of these structures solely from the classroom experiences they are provided. Thus, when teachers talk about particles, gases, the theory of heat, and so on, students perceive these theoretical approaches as completely irrelevant for their daily life, because they are unable to establish connections between them. But if students are encouraged to incorporate this knowledge into a specific epistemic practice –that is, if they are asked to articulate their knowledge to explain certain phenomena– they might understand that theoretical knowledge is constructed and developed to make sense of the world; and that this is useful and valuable *per se*. In addition to the aforementioned benefits for students' learning, the construction of explanations can also be a helpful assessment tool for teachers (Osborne *et al*., 2004) and students (Coleman, 1998).

Despite all these factors, and despite the number of parallelisms that can be found between the practices of explanation and argumentation, while there has been significant production of research focused on teaching science as argumentation, we cannot say the same about the number of studies centred in analysing the practice of teaching scientific explanations. The sections that follow can give us some clues to understand why this is so.

2.5.1. Scientific Explanation in Education policy documents

As previously noted, many scholars have argued that teachers should promote the acquisition of knowledge and skills that enable students to engage in the substantial epistemic practices of science, among which we find the formulation of explanations for natural phenomena (Berland & Reiser, 2009; Lehrer & Schauble, 2006). Equipping students with the ability to produce their own explanations –as opposed to merely reproducing textbook and teachers' explanations– is seen as critical for the development of scientific literacy (Bybee *et al.,* 2009; OECD, 2013; Ryder, 2001). Because of this, it has been adopted as a general educational goal in many countries (Millar & Osborne, 1998), either in the form of recommendations (e.g., in USA (NRC, 1996; 2013)) or within the compulsory curriculum (e.g., in England (Department for Education, 2014), Spain (MECD, 2013), Australia (ACARA, 2015), and Singapore (MOE, 2014)).

One document that attracted considerable interest within the science education community was *Breaking the Mould? Teaching Science for Public Understanding* (Osborne *et al.,* 2002), commissioned by the Nuffield Foundation. Among the objectives expressed in this report, it is stated that students should "develop an appreciation of the power of scientific explanations in helping to understand and control aspects of the natural world, whilst being aware of the nature of the limitations of scientific knowledge" (Osborne *et al.*, 2002, p.6). The authors of *Breaking the Mould* conclude that, although some changes can be seen in documents such as the National Curriculum for England (DfE, 1999) or the American National Science Standards (NRC, 1996), these would best be qualified as "piecemeal and tinkering at the edges rather than substantive" (Osborne *et al.*, 2002, p.15). The problem they note is that, in these documents, the construction of explanations is mentioned as a general objective, but poorly outlined and without manifestly indicating its relevance for students. This contributes to make it difficult for teachers to know what to do to achieve this goal in an effective way (Beyer & Davis, 2008; Saglam *et al.*, 2016).

In the current National Curriculum for England (Department for Education, 2014), it is established that students at Key Stage 3 "should be encouraged to relate scientific explanations to phenomena in the world around them and start to use modelling and abstract ideas to develop and evaluate explanations" (p.59), but it is not specified how to promote and achieve this goal. Similarly, in the Spanish Law for the Improvement of the Quality of Education (MECD, 2013) it is said that the teacher should be able to evaluate whether students are able "to formulate hypotheses to explain everyday phenomena using theories and scientific models" (p.258) but no further information for teachers to be able to interpret what this actually means and how to implement this in the classroom is provided.

Since teachers –especially, novice teachers– are usually guided by curricula, they might receive the implicit message that teaching how to explain is not essential for their classroom performance (Höttecke & Silva, 2011); or, at least, teachers might assume this is something unproblematic, perhaps to be spontaneously acquired by learners through exposure to science teaching that inherently encompasses instances of scientific explanation, but that does not require any specific pedagogic strategy. Consequently, students are given very few opportunities to engage in producing scientific explanations and to learn the fundamentals of this practice (Simon *et al*., 2006).

2.5.2. Scientific Explanation in Philosophy of Science

From what has been said in the previous section, we can infer that teachers struggle to create learning environments to foster students' proficiency to construct explanations, partly because this objective is vaguely presented in their reference documents. The origin of this vagueness may rest on the fact that in none of these documents is it manifestly defined what a scientific explanation is (Rönnebeck *et al.,* 2016). And since conceptual clarity seems to be the first step towards effective instructional practices (Braaten & Windschitl, 2011), the lack of an articulated conceptualisation of scientific explanations makes it difficult for teachers to systematically introduce this epistemic practice in the classroom (Russ, 2018).

Ennis (1979) submitted that, although it is quite rare for philosophers of science to show explicit concerns about the problems of science education, several questions that science teachers confront in their daily practice could be illuminated by the deliberations and investigations of those; one of these questions is, indeed, 'what is a scientific explanation?'. Given the central role that explanation plays in science, it is not surprising that this question had been the object of philosophical discussion for more than half a century (McCain, 2015). Despite some agreement on certain aspects of scientific explanation, philosophers do not possess a single theory of explanation accepted by everybody (Saglam *et al.*, 2016), as I show in the following sections.

2.5.2.1. The Covering-Law model

The essay of Hempel and Oppenheim (1948) is considered the first systematic attempt to lay the foundations of scientific explanation. This work proposes a model according to which an explanation is a deductive argument whose conclusion takes for granted the occurrence of the phenomenon to be explained. The conclusion -known as *explanandum*- is a proposition that describes the phenomenon. The premises of the argument compose a set of propositions adduced to provide a cognitive prop for the *explanandum*; they are known collectively as *explanans*. The *explanans* must contain sentences expressing specific antecedent conditions and sentences representing general laws. To count as an explanation, an argument needs to meet extra requirements: the *explanandum* must be a logical consequence of the *explanans*, and the *explanans* must have empirical content. Since the natural phenomenon is explained by subsuming it under general laws through a deductive argument, this model of scientific explanation came to be known as the Deductive-Nomological (D-N) or the Covering-Law Model.

The Covering-Law Model was widely criticised for many different reasons (Kitcher, 1989; Salmon, 1989; Scriven, 1988; van Fraassen, 1988). Hempel himself soon realised that not all legitimate scientific explanations are of the D-N variety. He introduced a new category –namely 'statistical explanations' (Hempel, 1965)– to refer to those explanations which use at least one statistical law. He distinguishes two logically different varieties of statistical explanations. The first one, known as Deductive-Statistical explanations (D-S), comprises cases in which the presence of statistical laws within the *explanans* does not modify the deductive nature of the explanatory process. Due to this, D-S explanations conform to the same general pattern as the D-N explanations. The second type of statistical explanation is what Hempel calls Inductive-Statistical explanation (I-S). In this case, the laws invoked in the *explanans* are statistical generalisations, and the event to be explained is inductively subsumed by the *explanans*; that is to say, the *explanans* simply assign a certain degree of support to the occurrence of the *explanandum*. While the D-S explanation type was conceived to give account of general regularities (e.g., why U-238 nuclei emit alpha particles) the I-S type was conceived to explain particular occurrences (e.g., Hempel's example of why Mr. Jones recovered from an infection when given penicillin).

2.5.2.2. The Causal-Mechanical Model

Salmon spent more than a decade trying to break with the hegemonic position that the Covering-Law Model had reached in the philosophy of explanation. The *coup de grâce* came with the publication of *Scientific Explanation and the Causal Structure of the World.* In this work, Salmon (1984) labels Hempel's views about scientific explanation as epistemic, to distinguish it from a completely different perspective, namely ontic, firstly proposed by Scriven (1975) and which Salmon himself subscribes. For the epistemic conception, scientific explanations are arguments. The ontic conception goes a step further, remarking that to explain a phenomenon by relating it to some antecedent conditions and laws is to place the event into an intelligible pattern. The label 'ontic' comes from the emphasis on existent physical relationships. Salmon submits that these patterns are usually causal; that is, in many cases, to explain a natural phenomenon is to identify and describe its causes, or to give the causal mechanism(s) that relates it to the premises (Salmon, 1978). Scriven (1975) had previously declared that causation is the relation between explanatory factors and what they explain. Railton (1981) stated that "causation seems to be the right kind of category to be fundamental in explanation" (p.192), something Machamer (1998) would subscribe to, since for him causality is "the key to unlocking the secret of explanation" (p.7). This approach to scientific explanations is commonly known as Causal-Mechanical Model.

Despite the attractiveness of the causal approach, it has the disadvantage of not being able to account for legitimate instances of non-causal explanations (Railton, 1981). This, added to the lack of a consensual definition for causality and the underdetermination of causes (Lipton, 1990), contributed to the emergence of alternative theories for scientific explanation. Even though the proposal of both the Unificationists (advanced by Friedman (1974) and further elaborated by Kitcher (1989)) and the Pragmatists (with Van Fraassen (1980, 1988) in the lead) are well-known cases, the establishment of the so-called 'New Mechanistic Philosophy' (Glennan, 1996; Machamer *et al.,* 2000) can also be seen as an answer to these problems without having to abandon the ontic conception of explanations.

2.5.2.3. New Mechanistic Approach

At the turn of the century, there was a shift in interest from singular to recurrent phenomena (Levy, 2013). As a consequence, the Causal-Mechanical Model evolved towards a more sophisticated account, known as 'Mechanistic Explanation' (Glennan, 1996; Machamer *et al.*, 2000), that remains as the most widely accepted account for explanation among scholars in many disciplines (Felline, 2018). According to this model, in many cases we cannot –or should not– explain a phenomenon only by citing its antecedent causes; it is also necessary to allude to the mechanism(s) responsible for the phenomenon to occur (Halina, 2017). Railton was one of the pioneers in bringing the notion of 'mechanism' into the philosophical literature on explanation, establishing that:

> "an account of scientific explanation seeking fidelity to scientific explanatory practice should recognize that part of scientific ideals of explanation and understanding is a description of the mechanisms at work, where this includes, but is not merely, an invocation of the relevant laws" (Railton, 1981, p.242).

Railton does not give a precise definition of 'mechanism', but he specifies that it is not a mere enumeration of causes. Salmon had expressed himself in similar terms a few years before, stating that:

> "(Scientific explanation) provides knowledge of the mechanisms of production and propagation of structure in the world. That goes some distance beyond mere recognition of regularities, and the possibility of subsuming particular phenomena there under. It is my view that knowledge of the

> mechanisms of production and propagation of structure in the world yields scientific understanding, and that this is what we seek when we pose explanation-seeking why questions." (Salmon, 1998, p.139).

Since these early attempts, many other philosophers worked on developing different analyses of mechanisms that lead to an alternative conception of causal-mechanical explanation. Although divergences can be found in the different Mechanistic proposals that have emerged, a common feature of all of them is to characterise mechanisms as complex systems. These efforts have crystallised in the establishment of the so-called 'New Mechanistic Philosophy' (Glennan, 1996; Machamer *et al.*, 2000)[2].

As can be noticed, in Philosophy of Science there exist a wide variance of approaches to scientific explanation, which makes the attribution of one unique meaning to the term, or one conclusive answer for what counts as a good explanation difficult. It is understandable, then, that science teachers had not been provided with a consensus model of scientific explanation (Saglam *et al.*, 2016). However, some ideas from the previous proposals can be selected and translated into teachers' language for methodological use, giving them a basis to broaden their knowledge about this science practice, as well as a guide to help them design learning environments where students' skills for constructing scientific explanations are fostered (Yao *et al.*, 2016).

2.5.3. Scientific Explanation in Science Education research

The numerous attempts by philosophers of science to provide an account of scientific explanation have not fully permeated into the educational realm. This results in a notable absence of academic papers describing how to perform this practice in the classroom (Tang 2016). Rönnebeck, Bernholt, and Ropohl (2016) acknowledge in their review that the limitations of the research literature are similar to those of the policy documents: most papers do not offer an articulated conceptualisation about the nature and function of explanations for educational purposes. To this, we must add that some authors see scientific explanation as unproblematic, others focus on only certain aspects of explanations, and, in some papers, explanation construction is not clearly distinguished from other practices, like argumentation (Braaten & Windschitl, 2011).

Beyond the problem of conceptualisation, it is possible to find some remarkable works which address students' difficulties to achieve proficiency in building scientific explanations. The

[2] For a further discussion on the notion of 'mechanism', go to A.1.3.

classical work that McCubbin (1984) carried out with college freshers revealed that these students struggle with constructing logically consistent explanations, even after several years of science instruction. More recent papers adduce that when students have to deal with explanatory tasks, they respond by using pre-causal explanations such as tautology, teleology, juxtaposition (McNeill, 2011), labelling, anthropomorphism, and knowledge justification (Taber & Watts, 2000). Although part of the difficulty to build explanations derives from a lack of knowledge base, McCubbin (1984) and others suggest that knowledge itself is not enough to engage students in such complex practice; therefore, it is necessary to deliberately teach how to formulate scientific explanations and to explicitly scaffold students in this effort (Kuhn, 1993; McNeill & Krajcik, 2006; Berland & Reiser, 2009; McCain, 2015; Yao *et al*., 2016).

The question that arises in this regard is whether teachers do possess the appropriate skills and expertise to effectively support and guide students' efforts to articulate scientific explanations. Many scholars have responded negatively to this question, emphasising that students are not the only group who find difficulties in constructing scientific explanations (Yao *et al.*, 2016). Horwood (1988), for example, claimed that some teachers confuse explanation with description, while Simon, Erduran, and Osborne (2006) add that teachers possess limited comprehension of how scientific explanations are developed. Other authors focus on the challenges that teachers encounter when scaffolding students in inquiry-based practices. Newton, Driver, and Osborne (1999) note that teachers lack the pedagogical skills needed to help students make sense of data and generate evidence-based explanations, while McNeill and Krajcik (2008) state that teachers lack the competences to create explanation-based learning environments.

Convinced that these problems must be addressed during the training period, Saglam *et al.* (2016) investigated 51 trainee teachers' beliefs about scientific explanation and their ability to explain natural phenomena. The data gathered at the beginning of the study revealed that, for a vast majority of the participants, an appropriate explanation was a short causal premise that could involve either a brief description or a theoretical account. However, after working in lessons purposely designed to enhance the quality of their explanations, the participants were able to learn what counts as a complete scientific explanation. Beyer and Davis (2008) conducted a single case study with Catie, a new elementary teacher, to elucidate which beliefs and knowledge she possessed about scientific explanation, as well as what instructional practices she implemented to assist students in this practice. The researchers supplied Catie with some inquiry-oriented materials, and then observed how she put them in action. After analysing the data collected through observations and interviews, Beyer and Davis concluded that i) Catie's understandings of scientific explanation comprised a multiplicity of meanings, including an everyday use of the term; ii) Catie thought explanation construction might be beneficial for helping students to understand their thinking; iii) the emphasis on explanation construction as an explicit learning goal was minimum; iv) Catie did not have a well-defined model to assess students' explanations.

Beyer and Davis (2008) address some final remarks to teacher educators and curriculum developers I find noteworthy because the first person blamed for deficiencies in teaching is often the teacher, which is not always fair (McCubbin, 1984; Newton *et al.*, 1999; Schulz, 2014). It seems clear that students cannot develop a deep comprehension about explanation if their teachers lack the knowledge necessary to create experiences and activities to drive their progress toward proficiency in this practice (Aydeniz & Ozdilek, 2015; Harlen & James, 1997). The same happens to teachers: since training programmes rarely include opportunities to practice the elaboration of scientific explanations (Richmond *et al.*, 2016), it cannot be expected that teachers can incorporate this practice into their classrooms (Zembal-Saul 2009). Beyer and Davis advocate for explicit and conscious training to enrich teachers' instructional strategies for fostering and scaffolding students' explanations.

Designing such training programmes would require a deeper understanding of the relationship between instructional practices and the development of students' explanatory skills. Two papers whose goal is to investigate this relationship are Lizotte, McNeill, and Krajcik (2004), and McNeill and Krajcik (2008). Lizotte and colleagues examine the use of three instructional practices –namely, 'defining scientific explanation', 'making the rationale of scientific explanation explicit' and 'modelling scientific explanation'– during a lesson. In McNeill and Krajcik (2008), 'connecting scientific explanation to everyday explanation' is added to the list. Both studies conclude that teachers' instructional strategies play a fundamental role in students' understanding and use of scientific explanations. However, while in the first paper (Lizotte *et al.*, 2004) the authors found that modelling the formulation of scientific explanations lead to greater student understanding of this practice, McNeill and Krajcik (2008) could not reproduce this result. Lizotte and collaborators also assert that defining the different components of explanation and providing the rationale behind this framework have a positive impact on student learning. McNeill and Krajcik do not contradict this affirmation, but they nuance it, by stating that these two instructional strategies only have a positive impact if they are provided in conjunction.

The need to focus on the teacher in the teaching-learning process of explanations construction is also reflected in Ruiz-Primo *et al.* (2010). At the outset, the aim of this study was to analyse the quality of students' written scientific explanations by using the Claim-Evidence-Reasoning framework, and to explore the link between the quality of these explanations and students' learning. However, what the authors found most interesting is the strong influence that different degrees of teacher's guidance had on students' outcomes. They concluded that the most suitable prompts for instructional and assessment purposes are those that allow students to provide pieces of information relevant to the explanations while doing their own thinking.

Despite the efforts made by the researchers cited, little is yet known about teachers' instructional practices and their influence on students' ability to elaborate scientific explanations (McNeill & Krajcik, 2008). Considering that for teachers any change in their teaching "is not just a case of developing a new skill but also one of developing a deeper understanding of the theoretical rationale of any practice" (Aydeniz & Ozdilek, 2015, p.338), they need a stronger theoretical basis to think about explanation. Something that might help science teachers in this complex mission is a working model of scientific explanations (McCain, 2015; Yao e*t al.*, 2016).

2.5.4. Towards an operational definition of 'scientific explanation' for this dissertation

As we have seen in previous sections, science education research literature, science curricula, and standards in several countries have emphasised the importance of involving students in the practice of constructing their own explanations for natural phenomena as a pathway to enhance scientific literacy (NRC, 1996; Osborne *et al.,* 2002; MECD, 2013; DfE, 2014; Ministry of Education, 2014; ACARA, 2015). However, as research has extensively shown, simply urging teachers to shift the focus in their teaching does not guarantee this will happen in the classroom, no matter how valuable the proposal might be (Braaten & Windschitl, 2011). Teachers need to be purposely prepared to acquire and understand the basic knowledge and skills required to teach this epistemic practice, as well as being supported to translate this understanding into effective models for performance. Moreover, teachers will need to consider how the introduction of explanations in their classroom fits into their beliefs system and orientations towards science, teaching, learning, epistemology and curriculum (Höttecke & Silva, 2011; Robinson, 1969).

Most authors in the field agree on two issues: i) students experience serious challenges in achieving proficiency in constructing scientific explanations (McCubbin, 1984; McNeill, 2011; Taber & Watts, 2000); and ii) the complexity of this practice demands it to be consciously and explicitly taught in science educational contexts (Kuhn, 1993; McNeill & Krajcik, 2006; Berland & Reiser, 2009; McCain, 2015; Yao *et al.*, 2016), and being continually reinforced (Taber 2013; Tang 2016). One way to overcome these difficulties might be to make available for teachers a simple but well-founded model that acts as a framework to understand what a scientific explanation is, while offering some guidance to develop learning environments where explanation building activities may be implemented (Magnusson *et al.,* 1999). The philosophical models of explanation that I summarised in Section 2.5.2 can provide science teachers with a good understanding of certain aspects of scientific explanations. However, as these models were conceptualised within a philosophical context, they do not account for how scientific explanations are constructed through oral and written language within educational settings.

Some researchers have accepted the challenge of developing such a working model to help teachers reduce the intricacy of the task of teaching how to build explanations. See, for example, Driver *et al.* (2000), Sandoval (2003), Erduran *et al.* (2004), McNeill & Krajcik (2006), Berland & Reiser (2009), and Ruiz-Primo *et al.* (2010). In all these works, the authors make use of Toulmin's analytical approach (Toulmin, 1958) as the basis for their educational framework for explanations. This framework –usually known as Claim-Evidence-Reasoning (CER)– is widely used across the science education research community. It is important to keep in mind, however, that the CER framework was originally conceived to characterise arguments, not explanations. One common approach taken by science education researchers adopting the CER framework to model explanations is to combine the pedagogical goals of both argumentation and explanation into a single practice called 'scientific explanation' (McNeill & Krajcik, 2006), 'constructing and defending scientific explanations' (Berland & Reiser, 2009), or 'knowledge building' (Scardamalia & Bereiter, 2006).

These views contrast significantly with the position adopted by Osborne and Patterson (2011). These authors ascertain that there is a confusion in how researchers use the terms 'argument' and 'explanation'; a confusion they seek to clarify. They think that this clarification is essential to define the nature of the activity that teachers expect their students to engage in, because a misconception could hinder effective teaching. Osborne and Patterson define both 'argument' and 'explanation' in a way so that the differences between them can be appreciated. Their stronger claim is that arguing and explaining are two different linguistic acts, with distinct epistemic functions: explanations aspire to provide understanding, while arguments aim to convince. Achinstein (1977) would use the term 'illocutionary acts' to refer to these practices which enclose different intentionality. For Osborne and Patterson (2011), the source of this difference is found in the degree of tentativeness of the phenomenon whose sense is intended to be elucidated; while in explanations the phenomenon is taken for granted, in argumentations, its degree of certainty is the object of discussion. For example, explaining why a stone falls to the ground if we drop it assumes the claim (and can assume the merits of the canonical criteria), but developing an argument to persuade physicists to consider gravity and electromagnetic force as the same type of interaction requires a different skills-set and different kinds of reasons. Aguiar (2016) draws a similar distinction, contemplating both epistemic and language considerations. For Aguiar, the main difference between both practices is that, while in explanatory communicative acts there is one privileged perspective –that of the canonical science–, argumentative communicative acts are opened to different voices, which will act through persuasion and discussion. According to Brigandt (2016), as these two practices have different epistemic goals, they need to meet distinct standards of adequacy.

Tang (2016) also aims to put an end to the conflation between explanation and argumentation. To do so, he takes some views from studies in the systemic functional linguistics. From this discipline, he brings the idea that explanation is a genre (or text type) whose schematic structure –consisting in Phenomenon, Identification, and Implication– makes it distinguishable from other genres. Tang recognises that the CER framework is suited for argumentation arising from empirical inquiry, but not for theoretical-driven explanations that aim to provide causal accounts of natural phenomena. Due to that, teachers need to adopt a different (albeit somewhat similar) rhetorical structure for scientific explanations to enable students to elaborate their own explanations.

Thus, given that (i) we engage in explaining and in arguing for different epistemic reasons, (ii) these two practices are characterised by specific and distinct rule-bounding sets (Chang, 2011); and (iii) the criteria to evaluate the quality of an explanation differ from those to assess the quality of arguments, it seems reasonable to conclude that the curricular model we aspire to develop to help teachers (and students) understand the logical structure of scientific explanations should not have Toulmin's argumentation framework at its basis. Rather, a different conceptualisation of scientific explanation in education must be proposed.

Despite not being an extensively explored area, it is possible to find some attempts to develop curricular models to support students' efforts to construct scientific explanations (Herrenkohl *et al.*, 1999; Sampson & Blanchard, 2012; Rönnebeck *et al.*, 2016). One well-known proposal is due to Braaten and Windschitl (2011). These researchers' objective is to elaborate a conceptual and pedagogical tool to help teachers to foster inquiry-based practices in classrooms. To do so, they create a mixed model by picking some elements from two accounts for scientific explanation elaborated by philosophers of science: the Causal-Mechanical model

(Salmon, 1978; Scriven, 1975) and the Unificationist model (Friedman, 1974; Kitcher, 1989), summarised in the so-called 'Explanation Tool'. According to this tool, three levels of explanation can be distinguished within a continuum: a low level of explanation, consisting of a description of a phenomenon without adducing theoretical components; a medium level that involves descriptions of how it happened, using theoretical components tangentially; and a high level of explanation, in which a causal account of why something happened is given.

The Explanation Tool, as its name indicates, may be a useful tool to evaluate different levels of proficiency in science students' explanations. However, what Braaten and Windschitl propose is a mere rubric, which does not constitute, in my view, a complete theoretical model as such. I agree with Woodward (1989) that any theoretical model of scientific explanation should provide an identification of the structural features that lead to the understanding of the phenomenon under study. Other researchers (Sampson & Clark, 2008; Wellington & Osborne, 2001) also note the structure of a scientific explanation as one of the key factors to measure the quality of the model. Therefore, when trying to conceptualise explanations in science classrooms, this aspect should not be ignored, and Braaten and Windschitl do not explicitly broach it. Another factor to evaluate the quality of a theoretical model is how it characterises the relevance relations between the different constituent structural elements that make an explanation explanatory. Without this, it is very difficult to achieve the two main goals to which any theory of scientific explanation should aspire: explanatory demarcation and explanatory normativity (Craver, 2014). Explanatory demarcation is understood as the practice of distinguishing explanation from other activities (e.g., description), while explanatory normativity refers to the criteria for distinguishing between successful and unsuccessful explanations (Halina, 2017). These goals can be dated back to Hempel (1965), who stated that we must identify the common structure and the set of conditions of adequacy of a scientific explanation to demarcate acceptable from non-acceptable explanations. The continuum presented by Braaten and Windschitl (2011) does not achieve either of these two objectives, because it is not very clear if descriptions are low-level explanations or something different, nor what a successful explanation within each level consists of. These critiques are partially solved by de Andrade *et al.* (2019), who use the same model but refine some aspects of it. In contrast to Braaten and Windschitl (2011), these researchers do qualify the descriptive explanations as pseudo-explanations, thus setting forth a much clearer demarcation criterion. This criterion is based on the qualities that de Andrade and colleagues establish any scientific explanation should possess to be considered satisfactory: relevance, conceptual framework, causality, and an appropriate level of representation.

Another paper that presents an instructional framework developed to help students build their scientific explanations is Tang (2016). He proposes a heuristic framework for explanation construction that he calls the Premise-Reasoning-Outcome (PRO) strategy. The premises in this model are either law-like statements (according to the D-N model (Hempel & Oppenheim, 1948)), or a general theory or big ideas (according to Unification models (Friedman, 1974; Kitcher, 1989)). The reasoning component refers to the implication sequences of successive clauses that lead to the causal account of the explanation. Finally, the outcome is just the phenomenon that it is intended to be explained. The PRO strategy is quite an interesting alternative to the CER framework for the analysis of explanations. However, I find a considerable fault in it: many explanations are not purely theoretical, but they demand some empirical background knowledge, and Tang omits this feature. Therefore, this model, although well-founded, does not have the degree of universality necessary to be established as the substitute for the CER framework.

Yao *et al.* (2016) take a step further toward an educational model for scientific explanation, suggesting one of the most complete and thorough-going proposals to date. These researchers adapt the syntax structure of explanations from Deductive-Nomological Model (§2.5.2). That is, they take from the Hempelian proposal the basic constituent elements of an explanation. The *explanandum* is re-designated as 'phenomenon component', and the *explanans* is split into 'theory component' and 'data component'[3].

We know Hempel's Model was strongly criticised by philosophers of science (Kitcher, 1989; Salmon, 1989; Scriven, 1988; van Fraassen, 1988). As these philosophers note, the D-N model falls short when it comes to accounting for what scientists really look for when they construct an explanation. The proposal of Salmon (1998) and others can alleviate this hurdle, but it is its sophisticated version, the Mechanistic explanation (Glennan, 1996; Machamer *et al.,* 2000), which has achieved the greatest acceptance by scholars. From a different perspective, Driver, Leach, and Millar (1996) argue that D-N explanations do not foster critical reasoning or deep conceptual understanding. The reason they adduce for this is that to decide whether a discourse is explanatory, it is also necessary to make explicit the association between the elements invoked to explain the phenomenon.

In response to these concerns, Yao and collaborators add 'reasoning' as the fourth component to their model. With this, they complete the so-called Phenomenon-Theory-Data-

[3] Throughout this dissertation, I have followed the terminology proposed by Yao *et al.* (2016), but I think it would be more accurate and enlightening to rename the theory component and the data component as 'conceptual component' and 'empirical component', respectively.

Reasoning (PTDR) framework for scientific explanation. In Figure 2.5, I display a graphic representation of the PTDR model. This picture depicts how both theories and background (empirical) knowledge are required, together with the phenomenon to be explained, as the necessary but not sufficient ingredients for the construction of the explanation. It also aims to reflect the fact that it is through the process of reasoning that the connections between these elements acquire meaning and, with them, the explanation of the phenomenon is completed, providing some kind of understanding of why the natural phenomenon occurs (McCain, 2015; Friedman, 1974).

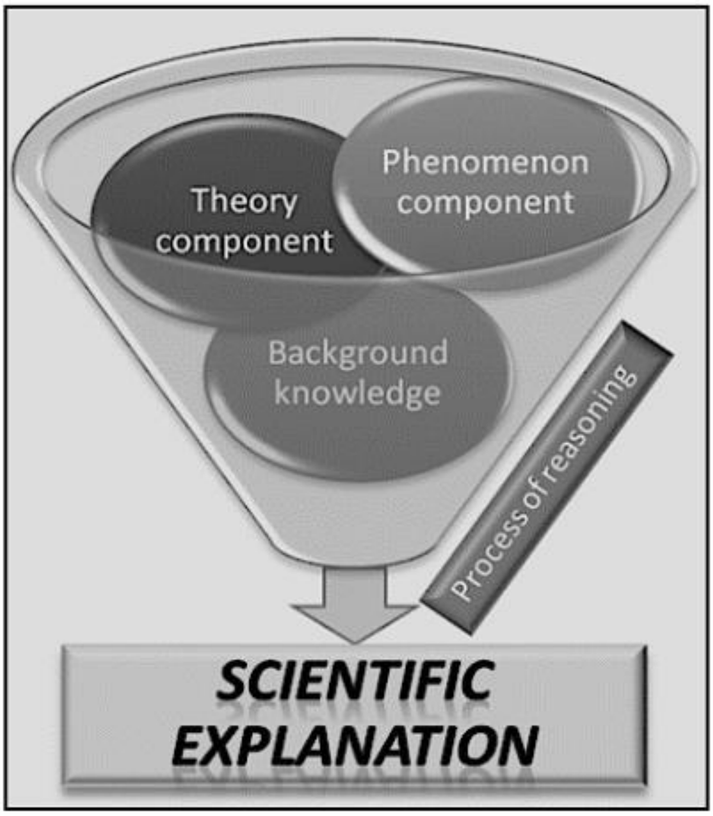

Figure 2.5.4. Educational Model of Scientific Explanation (adapted from Yao **et al.*, 20016)***

Although it requires further elaboration and refinement[4], I find Yao's proposal promising, elegant, and theoretically sound for two reasons: i) the PTDR model is, apparently at least, simple enough to be manageable by teachers. They could use it for planning explanation-based lessons, instructional design and scaffolding, and assessment; and ii) the PTDR model is rooted in some philosophical discussions about scientific explanation but does not have Toulmin's approach as its basis; that is, it has a rhetorical structure similar (albeit different) to the CER framework. This provides an acceptable response to objections raised by those authors

[4] Go to appendix A.1 for a thorough discussion on Yao *et al.*'s (2016) proposal.

that demanded a clear demarcation between argumentation and explanation (Brigandt, 2016; Osborne & Patterson, 2011; Tang, 2016).

From this framework, I characterise a scientific explanation as *an account based on the articulation of some theoretical knowledge and the interpretation of some empirical facts, which is constructed through a process of reasoning with the objective of making sense of a certain phenomenon.* I use this characterisation as my operational definition of scientific explanation for the rest of this dissertation.

2.6. Pedagogical Content Knowledge of scientific explanation

Throughout these pages, I have echoed the growing interest in the creation of learning environments that facilitate students' engagement into the authentic disciplinary practices of the scientific community, such as the articulation of explanations (Schauble, 2006). As a necessary step in fulfilling this task, I have provided an operational definition for scientific explanations. However, to increase students' explanatory competence, more is required than simply exposing students to a definition of what an explanation is; teachers have to design, guide, and scaffold both the instruction and the assessment procedures to take up the integration of the conceptual, social, and epistemic dimensions of this practice (Sandoval, 2003; Kang *et al.*, 2014; Stroupe, 2015). As I have noted, teachers find several challenges when trying to implement this into the science classroom, both pedagogical (e.g., what instructional strategies are more effective) and practical (lack of first-hand experience in constructing explanations, lack of time and resources). In order to overcome such difficulties, teachers need a particular type of knowledge that enables them to translate their understanding about scientific explanation as a practice into effective teaching strategies to engender individuals' paths towards proficiency. This knowledge is called 'Pedagogical Content Knowledge'.

In his speech at the American Educational Research Association meeting in 1985, Shulman named for the first time one type of knowledge that distinguishes the teacher from the scientist: the 'Pedagogical Content Knowledge' (PCK). Just as articulated in its beginnings, PCK includes the way of formulating and representing a topic to make it comprehensible to others (Shulman, 1986). For Shulman, PCK must be differentiated from other categories, such as knowledge of general pedagogy, knowledge of general educational purposes, and knowledge of learners' and contexts' characteristics. Moreover, as PCK concerns the 'how' and 'why' under the teaching of particular topics, it also differs from Subject-matter Knowledge (SMK) *per se*. It is important to notice that the possession of well rooted SMK is a necessary but not sufficient condition for developing a solid PCK (Abell 2008; Van Driel *et al*. 1998).

In a later work, Shulman (1987) refines his definition of PCK, emphasising that it is necessary to reflect not only on how to effectively manage students in the classroom, but also on the qualities, understanding and skills, that competent teachers need to effectively manage ideas. In this paper, Shulman includes PCK as one of the seven components of the basic knowledge all teachers should aspire to possess; these components are i) Content Knowledge; ii) General Pedagogical Knowledge (including principles and strategies of classroom management and organisation); iii) Curriculum knowledge (including materials and programmes); iv) Pedagogical Content Knowledge (a combination of content and pedagogy exclusive to teachers; v) Knowledge of Learners (including knowledge about their individual differences and common difficulties); vi) Knowledge of educational contexts (from the classroom to communities and cultures, stopping over on the school district); and vii) Knowledge of educational ends, purposes, and values, and their philosophical and historical grounds.

Since its inception and subsequent refinement, PCK has been revised and extended by many researchers (Tamir, 1988; Grossman, 1990; Geddis *et al.*, 1993; Van Driel *et al.*, 1998; Magnusson *et al.,* 1999; Loughran *et al.*, 2012). The strategies these researchers followed to characterise PCK can be split into two groups: some focused on modifying Shulman's definition, while others aimed to identify central components constituting PCK and then to describe it as an integration of those components. In the first group, we find Geddis, Onslow, Beynon, and Oesch (1993), who defined PCK as the knowledge needed to transform subject knowledge into something comprehensible to students. Likewise, Carter (1990) characterised PCK as what teachers know about how to transform their subject knowledge into curricular events.

Among those who wanted to identify the basic components of PCK, Tamir (1988) stands out as a pioneer. Keeping in mind the question 'What kind of knowledge do teachers need in order to be effective in their classrooms?', Tamir offers a definition of PCK (which he refers to as 'Subject Matter Specific Pedagogical Knowledge') that is parcelled into four knowledge domains: Student, Curriculum, Instruction and Evaluation. Grossman, a student of Shulman, followed a similar path, proposing a model of teacher knowledge that also comprises four domains, being these Knowledge of Students' Understanding, Curricular Knowledge, Instructional Knowledge and Conceptions of Purposes for teaching subject content (Grossman, 1990).

Complementing both the Tamir and Grossman theoretical proposals with some empirical data, a few years later, Magnusson, Krajcik, and Borko (1999) proposed a five-components structure for PCK, which is why the model became known in the academic literature as 'the Pentagon model' (Park & Chen, 2012). In their description of the PCK components, Magnusson and colleagues talk in terms of 'knowledge and beliefs' as opposed to only 'knowledge', which was the common trend. The Pentagon model (Figure 2.6) is still one of the most widely used models to describe PCK in the science education literature. The five different but interconnected components that compose PCK are:

i) Orientations toward Science and science teaching (OTS) → This component refers to teachers' knowledge and beliefs about the purposes for teaching science at different grade levels (Grossman, 1990), the nature of science, and the teaching-learning process itself (Friedrichsen *et al.*, 2011). Two types of goals have a place in OTS: central –those goals that direct teachers' decisions about their practice– and peripheral goals –those that have limited effect on teachers' practice (Friedrichsen & Dana, 2005). The OTS component has an overriding role in PCK, since orientations serve as a conceptual map for decision-making relative to organising and performing teaching (Magnusson *et al.*, 1999).

ii) Knowledge of Instructional Strategies and representations (KIS) → This component involves two categories: subject-specific strategies and topic-specific strategies (Magnusson *et al.,* 1999). Subject-specific strategies are general approaches to instruction that are consistent with the goals of science teaching in teachers' minds, such as inquiry-oriented instruction. Topic-specific strategies refer to specific activities and representations that apply to teaching particular topics within a domain of science.

iii) Knowledge of Students' Understanding of Science (KSU) → This component refers to teachers' knowledge of what students know about a topic or practice, including students' most common conceptions and misconceptions, learning difficulties, and plurality in learning styles, interest, abilities, motivations and needs (Aydin & Boz, 2013).

iv) Knowledge of Science Curriculum (KSC) → This refers to teachers' knowledge about prescribed goals and objectives, as well as curricular programmes and materials available for teaching particular subject matter. Grossman (1990) includes here the knowledge of both the curriculum for a specific age range ('horizontal curriculum') and what is studied in earlier and later years ('vertical curriculum') for a subject.

v) Knowledge of Assessment of Science Learning (KAs) → This component (fist proposed by Tamir, 1998) comprises knowledge of the dimensions of science learning important to assess, and knowledge of the methods, specific instruments, approaches and activities by which that learning can be assessed.

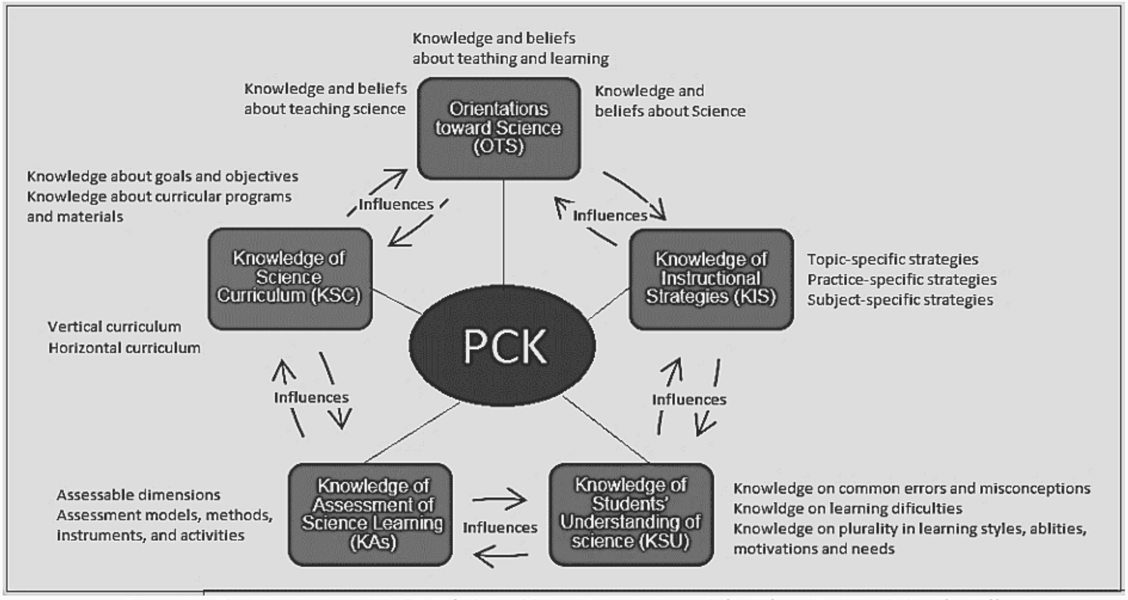

Figure 2.6. The Pentagon model of PCK (adapted from Magnusson et al. (1999) and Park and Chen (2012)).

There appears to be agreement among scholars that PCK is not fixed, nor final (Bond-Robinson, 2005; Grossman, 1990), but promoted through an integrative and non-linear process (Bergqvist, 2017) founded on i) teachers' prior learning -both as students and as student teachers-; ii) personal backgrounds; iii) educational contexts; iv) classroom practice; and v) teacher preparation programmes and professional development opportunities (Akin, 2018). Because of this, PCK is idiosyncratic (Loughran *et al.*, 2004; Park & Chen, 2012), being the nature of development different for each teacher (Van Driel *et al.*, 1998; Simon *et al.,* 2006). Nevertheless, the PCK of different teachers may also have some common characteristics and components (Park & Oliver, 2008). The delimitation and representation of these common components can contribute to researchers' understanding of *how* and *why* teachers teach the way they do (Loughran *et al.,* 2012).

For successful teaching to occur, teachers must possess a high level of knowledge in every single category of PCK (Hashweh, 2005), but there must also exist a coherent integration of all these components within a given context. Improvement within a single component may not be sufficient to amend the quality of the whole PCK (Magnusson *et al.,* 1999) and how it is put into action (Abell, 2008). Moreover, there are many studies that indicate that teachers' values and beliefs have a strong influence on PCK development, and also a well-founded SMK (Kind, 2009). In addition to this, research about PCK ascertains that the acquisition and use of this kind of knowledge is interwoven within the context of instructional practices, and therefore, the integration of all the components requires the complementary and open-ended readjustment by both reflection-in-action and reflection-on-action (Aydin & Boz, 2013). The nature and dynamics of this process is still only scarcely understood, and so it is not easy to assure how to success in PCK improvement (Park & Chen, 2012).

Most research on PCK is devoted to science topics (e.g., optics (Alonzo *et al.,* 2012)) or disciplinary core ideas (e.g., chemical equilibrium (Van Driel *et al.*, 1998)). However, there are authors who venture that the definition of PCK given here may also apply to the PCK of scientific practices (Knight-Bardsley & McNeill, 2016; Osborne, 2014). Davis and Krajcik (2005) emphasise the necessity to analyse PCK of disciplinary practices as a distinct aspect of PCK. Since “students cannot comprehend scientific practices, (…), without directly experiencing those practices for themselves” (NRC, 2013, p.v), teachers need to know how to help students engage in them. This requires a consideration of students’ actions and interactions within the classroom setting which may differ from other learning goals. Producing scientific explanations and arguments are two disciplinary practices for which teachers may require specialised PCK to successfully integrate them into their classroom instruction.

Although to date, few researchers have focused on teachers’ PCK of scientific practices (Osborne, 2014), we can find some good exemplars of PCK studies examining scientific argumentation (Knight & McNeill, 2011; McNeill & Knight, 2013; Suh & Park, 2017; Wang & Buck, 2016; Katsh-Singer, 2016). McNeill and Knight strive to work out what the relationship between teachers’ PCK of scientific argumentation and their classroom practice is, to elucidate why students are given so few opportunities to participate in argumentation in science lessons. To do so, their first step is to conceptualise the specialised PCK for argumentation. The elements they consider that teachers must possess are i) the structure of an argument and the nature of argumentation; ii) students’ conceptions of argumentations; and iii) effective instructional strategies for argumentation (McNeill & Knight, 2013). These two authors selected some participants of their series of Professional Development workshops and examined their PCK of argumentation, their beliefs about the value of argumentation, and how they incorporated the CER framework into their classrooms (this last question, only in Knight & McNeill, 2011). The most promising result of these works is that, against what McNeill and Knight had hypothesised, the relationship between PCK and belief with respect to practice is bidirectional. And also, that PCK can be improved through purposely designed workshops.

Suh and Park (2017) aimed for identifying common patterns of PCK in some teachers who had implemented an argument-based inquiry approach. By comparing and contrasting three cases, they found that: i) teachers’ orientations to how students learn, the nature of science, and the role of language in science are critical active factors for significant changes in PCK and practice to adopt argument-based inquiry; ii) a strong integration and alignment between Orientations, Knowledge of Student Understanding, and Knowledge about Instructional Strategies is essential for the sustainability of argument-based environments; and iii) Knowledge of Science Curriculum and Knowledge of Assessment are the less frequently incorporated components into the teachers' PCK.

Wang and Buck (2016) were interested in understanding argumentation from science teachers' perspectives. For this purpose, they investigate Mr. Jack –a physics teacher– in the context of dialogic argumentation. By using Magnusson's pentagonal Model, they map out the teacher's PCK of argumentation and conclude that, for Mr. Jack, argumentation is not one fundamental objective all the students should master, but a mere instructional tool that may be suitable for some particular students. A second finding that may be valuable for my own research is that the assessment of argumentation is a highly difficult task for science teachers, so they would require reliable and applicable rubrics.

As far as I know, there are no existing examples of studies whose explicit goal is to conceptualise and explore PCK of scientific explanation. However, understanding teachers' PCK of this scientific practice would be necessary to better grasp and improve the implementation of explanation-based practices in the classroom. Moreover, if we aspire to design teacher education experiences and training programmes in balance with educational reforms, we should try to portray teachers' PCK of scientific explanation and to enlighten the influence that this knowledge may have on instruction (Schneider & Plasman, 2011). My research project was conceived as an attempt to respond to this call. The operational definition of PCK taken for this research is a modified version of the ones proposed by Loughran *et al.* (2000) and Carlson *et al*. (2015). Thus, PCK of a scientific practice will here refer to the particular knowledge that a teacher possesses –and the reasoning behind– which enables her to teach such practice it in a way that best engenders students' understanding and progression.

CHAPTER 3. RESEARCH DESIGN

3.1. Overview

The design of a research project consists of several phases, from the selection of the topic of interest to the communication of the findings (Barriball & While, 1994). In Figure 3.1, I offer a representation of the different stages of my research study, which correspond to the different sections of this chapter. Each step within the design process have some potential influence over the outcomes of the investigation; therefore, we researchers must be consistent and transparent about the choices made, and "avoid as much error as possible during all phases of the research in order to increase the credibility of the results" (Brink, 1991, p.166).

RESEARCH PARADIGM	Paradigm 2 (EPR2): Descriptive, Naturalistic and Idiographic		
METHODOLOGY	Case Study: Multiple and Exploratory		
SAMPLING	Pilot Stage: convenience sample	Fieldwork Stage: Exploratory sample (Purposive)	
DATA COLLECTION METHODS	Observations: Non-participant, unstructured, based on narrative and technological recording	Semi-structured interviews	Fieldnotes
DATA ANALYSIS METHODS	Constant Comparative Method: Preliminary Coding + Open Coding + Pattern-Seeking → Categories and Themes		

Figure 3.1. Methodological framework of the thesis

Chapter 2 provided a description of the first step: the selection of the research topic. In that chapter, I presented a conceptual framework to justify why science teachers should include the core practice of explanation construction in their classrooms, as well as some difficulties that could arise in the process. It would be convenient to keep in mind some ideas reported, including: i) teachers need to explicitly teach how to produce scientific explanations in order to engage students in such practice (Berland & Reiser, 2009; Kuhn, 1993; McCain, 2015; McNeill & Krajcik, 2006); ii) teachers possess limited understanding of how explanations are developed (Erduran *et al.*, 2004); and iii) teachers lack the pedagogical skills needed to help students generate explanations (Newton *et al.*, 1999). Based on my review on diverse research areas, I propose that to overcome these difficulties, teachers require a particular type of knowledge – called 'Pedagogical Content Knowledge' (Shulman, 1986)– and a working model for explanation

–the Phenomenon-Theory-Data-Reasoning (PTDR) model (Yao *et al.,* 2016), presented in section 2.5.4, seems an appropriate candidate–.

The ideas just summarised acted as a baseline for shaping the research problem of this dissertation; namely, what knowledge and beliefs teachers possess about scientific explanation and how they introduce and evaluate this practice in their classroom. The research paradigm, methodology, and the methods employed to address this problem are examined in this chapter. This account requires the inclusion of details about how the participants were selected, the data collected, and the techniques used to analyse them.

3.2. Research Questions

Generally, the step following the choice of the topic is not the same in quantitative and qualitative designs. While, in quantitative studies, the second step is to set forth a testable hypothesis, in qualitative ones, the most usual is to propose a set of research questions (Agrees & Agee, 2009). Research questions narrow the inquiry process from a mere expression of interest to a concrete problem (Cohen *et al.,* 2007). Furthermore, these questions channel the methodology and the methods for data collection and analysis (Taber, 2013). In my case, the literature review led me to the problematic phenomenon –present in both policy and academic documents– of explanation construction in science classrooms.

The triggering question I selected to explore this phenomenon was: What is teachers' Pedagogical Content Knowledge of scientific explanation? (*Q1*). Since *Q1* seemed too broad, I decided to break it down into three sub-questions. Some writers refer to these sub-questions as 'issue questions' (Creswell, 2013), since they trace a procedure for analysing the collected data and identifying categories.

Given that qualitative research is "an emerging design" (Creswell, 2013, p.130) in which some elements "may only emerge after the researcher has been immersed for some time in the research site itself" (Cohen *et al.*, 2007, p.174), it is not uncommon, as the investigation progresses, for questions to arise that had not been initially considered; this is especially relevant in exploratory case studies, like the one I present. After having interviewed two participant teachers, I realised that there was an issue about which both, independently and almost spontaneously, had shown certain concern. I found the issue interesting and worth investigating since it fitted well with the objectives of my research. To delimit it as a problem and thus be able to incorporate it systematically into my observations and interviews, I formulated this emerging issue as another research question, as shown in Table 3.2.

Table 3.2. Research questions.

RESEARCH QUESTIONS
Q1. What is teachers' Pedagogical Content Knowledge of scientific explanation?
Q1a. What ideas, knowledge and beliefs do teachers hold about scientific explanation?
Q1b. What instructional practices do science teachers engage in during science lessons to support students in constructing scientific explanations?
Q1c. How do teachers assess students' attempts to construct explanations?
Q2. What do teachers perceive to be the fostering and/or hindering conditions for the teaching of scientific explanation construction in the classroom?

3.3. Research Paradigm

Echoing Kuhn's ideas, Popkewitz (1984) claims that research paradigms provide an institutional response to unsolved questions within a field of knowledge. Research paradigms draw upon different ontological, epistemological and methodological assumptions (Gilbert & Watts, 1983; Cohen *et al.,* 2007; Bryman, 2012; Taylor, 2014), which have significant consequences for the development of the inquiry and the interpretation of the findings (Guba & Lincoln, 1994). Willis, Jost, and Nilakanta (2007) shape up this idea by stating that "different paradigms lead us to ask different questions, use different methods to study those questions, analyse our data in different ways and draw different types of conclusions from our data" (p.xx).

Gilbert and Watts (1983) sketch an accurate description of two paradigms for education research, which they refer to as 'Paradigm 1' and 'Paradigm 2'. Studies under Paradigm 1 or ERP1 (Taber, 2013) have explanation as their goal. They are usually based on a realist worldview, with researchers adhering to an empirical-inductivist and positivist notion of knowledge (Glesne, 1999). The social world is regarded as made up of observable, measurable facts, and predictable and regular patterns (Burton & Bartlett, 2009). Since researchers are interested in the discovery of general laws, studies carried under ERP1 are nomothetic. These features point to a quantitative treatment of data, which, in turn, points to the use of representative samples of the population under study. One disadvantage of the ERP1 approach for education research is that the results under this paradigm are usually insensitive to local contexts and individuals (Taylor 2014). This conflicts directly with the purposes of my research and with the rationale under case study approach. Consequently, my project could not be located within Paradigm 1.

Researchers that opt for Paradigm 2 or ERP2 (Taber, 2013) are interested in understanding social phenomena, so they tend to focus on descriptions. The approach to phenomena under this paradigm is holistic, naturalistic and idiographic, given that it relates to the study of individuals in context-specific situations, without being generalisations their central goal. ERP2 researchers reject the idea of an objective reality that exists irrespective of people; external reality is seen as a construct of the human mind (Bassey & Coate, 1999; Burton & Bartlett, 2009), and therefore, variable: "realities are apprehendable in the form of multiple, intangible mental constructions, socially and experientially based, local and specific in nature (…), and dependent for their form and content on the individual persons or groups holding the constructions" (Guba & Lincoln, 1994, p.110). This has important implications on what is perceived to be the nature of knowledge. Researchers under this paradigm deny the existence of objective knowledge, since "meaning emerges through interaction and is not standardized from place to place or person to person" (Rubin & Rubin, 1995, p.31). Meaning, then, has to be interpreted, preferably in terms of the actors involved (Denzin & Lincoln, 1994). Cassell and Symon (1994) declare that qualitative approaches *emerge* from interpretive paradigms, since its terminology is the result of the translation of terms aligned with the interpretive perspective. Therefore, studies under this paradigm usually demand qualitative designs.

Every research study must be located within a particular paradigm. This requires an alignment between the researcher's thinking patterns and research actions, and the ontological and epistemological views dictated by the paradigm (Bassey & Coate, 1999). Because of this alignment, the study can only be judged under its paradigm's terms (Golafshani, 2003). The definite paradigm, applicable to any work, does not exist; different paradigms are suitable for different research goals. Thus, the guiding principle for selecting a paradigm must be 'fitness for purpose' (Cohen *et al.*, 2007). My research goal was to portray science teachers' PCK and beliefs about scientific explanation, as well as the strategies they implement to assist and evaluate student's engagement on this epistemic practice. I also aimed to disclose the factors that teachers perceive as facilitators for the inclusion of explanatory practices in the classroom, and which ones they see as an obstacle. These goals pointed to ERP2 as the appropriate paradigm within which to frame my project.

3.4. Methodological approach

When embarking on a research study, a plan of action on how the inquiry should proceed must be carefully considered. This is what we call 'methodology' (Taber, 2013). In a broad sense, the methodology acts as a nexus between the ontology, the epistemology and the theory underpinning a project, and the actual practice (Hetherington, 2013). In concrete terms, it leads the selection and sequencing of the methods for data collection and analysis, connecting them to the final outcomes (Crotty, 1998).

Explicitly stating the methodology chosen for a study is fundamental to guarantee transparency about what the researcher did, how it was done, and what must still be done (Maxwell, 2005). This transparency is specially necessary in qualitative research, where critiques about interpretive subjectivity and the possibility of providing conclusions without enough supporting evidence are a commonplace (Barreto-Espino, 2010). In this section, I address these issues by delineating the qualitative methodology in which I decided to frame my study on teachers' Pedagogical Content Knowledge of scientific explanation.

The assumption that PCK is a variable, personal, and complex construct (Loughran *et al.*, 2004; Abell, 2008; Park & Chen, 2012) demanded a methodology sensitive to individual variation and based on a strong interaction between researcher and participant. The case study approach is described as being sensitive to such idiosyncrasy (Yin, 1981) and such complexity (Byrne 2005), so it was selected for this work.

Denscombe (2010) defines case study as a methodology used to investigate "one (or just a few) instances of a particular phenomenon with a view to providing an in-depth account of events, relationships, experiences or processes occurring in that particular instance" (p.35). Macdonald and Walker (1977) highlight that the instance(s) must be studied *in action*. Cohen *et al.* (2007) summarise these two conceptualisations by affirming that case studies may provide unique examples of "real people in real situations" (p.253), making possible a deep comprehension of a research problem.

Despite some initial reluctance, researchers in education today accept case study as an adequate methodology for investigating the dynamics of certain aspects of educational phenomena (Eisenhardt, 1989; Merriam, 1988), particularly in small-scale research (Denscombe 2010). This acceptance is rooted in Yin (1981, 1994, 2003) and Stake (1994, 1995, 2000, 2005), among others. According to these authors, what characterises researchers under the case study approach is their desire to understand both the singularity and the complexity of an individual instance. To do so, researchers need to analyse the relationship between different features of the phenomenon and its environment. Scholars insist on this necessity of setting the case within its context, rather than attempting to isolate it: "a case is a bounded system", claims Stake (2000, p.2), although "the boundaries between phenomenon and context are not (always) clearly evident" (Yin, 1994, p.13).

A category that researchers usually consider to be more solid and convincing than single-case designs (Yin, 2009) is constituted by what Stake (1995) calls 'multiple case study'. When the same phenomenon is thought to exist in a variety of situations, or when seeking an increase in the generalisability of the results (an issue discussed in §6.3), it could be helpful to choose several instances to study rather than just one.

Conducting a multiple case study comes with both advantages and difficulties. The main advantage is that it allows a wider exploration of the research questions, opening the door to theory development (Eisenhardt & Graebner, 2007). However, the amount of data needed for these studies makes them quite time-consuming[5] (Baxter & Jack, 2008). Another challenge for researchers within this approach is not to overlook the individualities of each case in the search for patterns. To avoid this, Eisenhardt (1989) suggests a progressive advance through different layers of analysis. The first focus of analysis should be the particularities of the individual cases. Once completed this within-case layer, the analysis should progress toward the search of commonalities across instances. I introduced this layer-based analysis in my research, leading to the results reported in Chapters 4 and 5, respectively. I found this kind of analysis highly valuable to elucidate those aspects of teachers' PCK that might transcend context and be established as canonical.

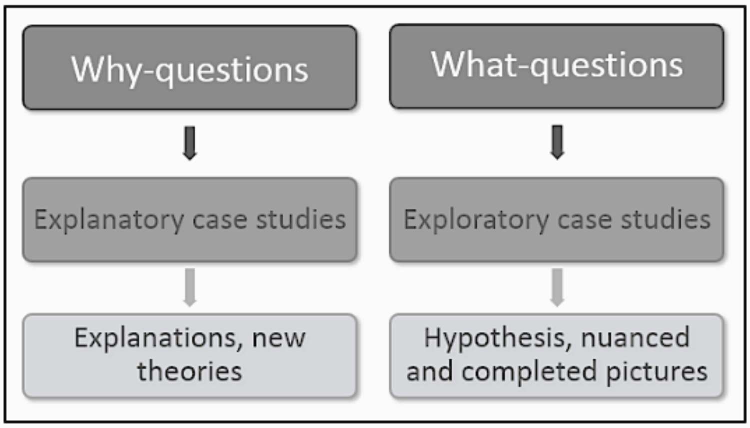

Figure 3.4. Differences between explanatory and exploratory case studies.

Case studies can also be classified as either explanatory or exploratory (Yin, 1981, 1994, 2009). As its name implies, explanatory case studies aim to develop and test explanations for why specific events occur. On the other hand, exploratory case-study researchers seek to identify some relevant categories of meaning about phenomena with no clear outcomes (Yin, 2009) to develop a nuanced and more complex picture of them (Flyvbjerg, 2006). Since exploratory studies are usually data-driven and inductive (Taber, 2013), the inquiry process might also lead to the generation of hypotheses for further research (Marshall & Rossman, 2016). That a study is categorised as exploratory or as explanatory depends on the researcher's

[5] As an example, the data for this thesis were collected over a period of four months which lead to over 175 hours of audio recordings, and around 130000 words of transcribed text.

goals (reflected in the type of research questions, Figure 3.4) and the degree of development of the given topic (Yin, 1981).

In Table 3.2, I present my research questions. They are 'what' and 'how' questions whose answers might help i) portray teachers' conceptual, pedagogical and practical knowledge on how to guide and scaffold the construction of scientific explanations; ii) create a coherent picture of the existing situation of how students are actually taught to build scientific explanations; and iii) start developing our understanding of the possibilities for promoting this epistemic practice in science lessons. There are some suggestions documented in the academic literature about these issues, but virtually no real discussion about them (Aydeniz & Ozdilek, 2015), so an exploratory case study seemed the most suitable methodology for my research.

3.5. Participants of the study

Understanding complex phenomena in depth usually requires collecting huge amounts of data during long periods. This favours that the relationship between researcher and research participants evolves and narrows as the investigation advances (Mertens & Ginsberg, 2014), becoming so close that the findings may be "more a negotiation than a discovery of what is the case" (Pring, 2000, p.41). Seidman (1998) would add that the connection between the researcher and the participants in case studies is not just strong but also unique, since it reflects their personalities. These considerations made me conceive the selection of the sample as a cornerstone within the research design process.

To understand the kind of sample chosen, we need to bear in mind the interpretive-qualitative and exploratory nature of my study. What Merriam (1988) calls 'exploratory samples' may give access to the different ways in which a phenomenon is experienced within a chosen context. One of the best techniques to constitute an exploratory sample is the purposive selection (Etikan *et al.,* 2016), where participants are deliberately selected expecting they can provide quality information and valuable insights on the research topic based on their knowledge, experience, and their ability to reflect about it (Maxwell, 2008; Morse, 1994). Purposive sampling used in such an exploratory way can be especially useful for small-scale case studies like this, because it allows the creation of a comprehensive product (Barreto-Espino *et al.,* 2014).

Exploratory samples with purposely selected participants are appropriate when dealing with relatively unexplored topics (Denscombe, 2010), so that it is preferable to maximise variety. I was interested in examining naturally occurring contrasts in teachers' ideas and instructional practices regarding scientific explanation. Thus, participants were sampled attending to diversity in three aspects: i) type of school (to include the interactions between teachers and their environment), ii) teaching experience, and iii) science specialism (because of the fundamental relationship between PCK and science content knowledge). In fact, what I selected were some schools that could meet those criteria; then, teachers within the schools volunteered to participate. Therefore, I could decide the number of science teachers to include in my sample, as well as other aspects such as the time to work with them and what data would be realistic to collect, but the final participants were those who were willing and available at the time to be studied.

Before starting the fieldwork period, I emailed a couple of schools in Seville (Spain), which I reckoned satisfied my requirements: an independent school and a state high school. I received a positive response from both. After a first interview with the potential participants, I decided to include in my sample only the independent school. I was convinced that teachers from this centre could provide some enlightening results, although I was aware it might be considered an extreme or deviant case (Creswell, 2013) regarding size, type of learning strategies used, and teachers' experience in practice-based teaching[6].

The second school I chose was a state high school in Madrid. The selection process for this centre was somewhat different. One of the teachers at that school has been an acquaintance of mine for years. From the moment he heard about my PhD research, he was enthusiastic about it and wanted to be one of the participants. I found his school very interesting for my study mainly because it was completely different from the first one that I had already selected. Moreover, while the first school could be viewed as a deviant case, this one was more typical/standard, in terms of type of school, size, number of students and teachers, pedagogical orientation of the staff, and students' socio-economic background (see 'School-A', §4.3)[7]. The teacher who had shown interest in getting involved in my project asked his colleagues in the science department to join us, and three of them accepted. Although I started the observations

[6] The reason why I left the high school in Seville out of my study is that I had the impression that teachers were a bit reluctant for me to observe their classes, and that they were somehow forced by the Headmaster to participate in the project. We have seen that, in case study methodology, a high level of participant engagement and trust with the researcher is fundamental for the correct development of the research; therefore, a group of teachers who did not feel comfortable with me and did not seem too interested in my research would hardly become good informants (Merriam, 1988).

[7] All the participant teachers from the schools in Madrid and Seville were native Spanish speakers. Thus, the lessons, written materials and other resources used by teachers in these two schools were in Spanish – except in those groups that were part of the bilingual program in Madrid (§4.3). The interviews I conducted in these schools were held in Spanish.

with all four, only the data of two participants (Alba and Adrian) were analysed, and only Adrian's case was included in the main text of this dissertation[8].

Something characteristic of exploratory qualitative research is that the data analysis is conducted simultaneously with the data collection (Coffey & Atkinson, 1996), at least in part. Thus, in the process of elucidating the meaning of what is being observed, some tentative categories and themes may emerge. These may be tested out as the study proceeds, either by checking them with the sample already observed or by conducting additional observations (Simpson & Tuson, 1995). While being in School-A, some pertinent questions that I had not considered during my research planning stage arose. To this, I must add that, also during my stay in Madrid, I realised that i) the school culture and the type of educational system could have more influence on whether teachers included the formulation of explanations in the classroom than I had imagined; and ii) the number of episodes in which teachers asked students to build an explanation for a natural phenomenon was so low, that I could hardly have enough data to make a characterisation of their PCK for this practice. For these reasons, I decided to increase my sample. Since by then I was already back in Cambridge, for geographical convenience, I continued my research in some English schools. In the long run, this turned out to be a wise decision since it allowed me to observe some promising differences between the two educational systems[9]. To select the new participants, I followed the same procedure as in Seville; namely, I chose four schools that fitted my requirements –two State schools and two Independent schools– and contacted them to gauge their interest in getting involved in my project. One school of each type emailed me back with a positive reply.

One of the respondents was Christian, a teacher who was already familiar with my research interests and the way I conduct my observations because he had already been part of the pilot stage of my research (see Appendix A.2). During the week I had spent observing Christian, I witnessed a couple of episodes in which he put into practice some specific strategies

[8] Álvaro, the least experienced teacher, was transferred to another school before finishing my observation period with him. In the case of Annabelle, we could not conduct the interview and part of the observations because her son fell ill, and she had to be absent for several days. Both Álvaro and Annabelle were really kind, solicitous and thoughtful during the time we shared. And although my experience with them could not finally be included in this thesis, I must say it was fully satisfactory.

[9] This statement could perhaps lead the reader to think that mine is an international comparative study. Despite being an interesting research route, this is not the case. In sections 4.2 and 4.5, I present a brief description of the educational system of Spain and England, the countries in which the data were collected. The purpose of this was that the reader could familiarise with some aspects of the participants' contexts. However, I did not intend to establish a connection between the differences across participants and the countries where they work. With a broader and more representative sample, this could be a stimulating line for further research.

to help his students to build an explanation for a given phenomenon. This is the main reason why I requested Christian to also participate in the main empirical stage of my study. Although the other science teachers from School-C were also invited to participate, none of them accepted[10]. Like the Spanish Independent school, this educational site was an interesting case in itself, albeit somewhat deviant in terms of size, pedagogical strategies and students' socio-economic backgrounds (detailed in §4.6).

Table 3.5) Background details of the participants of the study.
**Instruction languages: Sp – Spanish; En – English; Fr – French. **Subject not included in the study.*

TEACHER	ADRIAN	ALBA	BECCA	BARNEY	CHRISTIAN
SCHOOL	**A**. State High School (Madrid)	**A**. State High School (Madrid)	**B.** Independent School (Seville)	**B.** Independent School (Seville)	**C.** Independent School (Cambridge)
EDUCATION	B.Sc. in Chemistry PGCE in Secondary Science	B.Sc. in Chemistry PGCE in Secondary Science	B.Sc. in Chemistry QTS	B.Sc. in Biology QTS	B.Sc. Environmental Chemistry PGCE in Secondary Science
TEACHING YEARS	<5	<4	12	12	14
TEACHING SUBJECTS	Physics and Chemistry (Sp*and En*)	Physics and Chemistry (Sp*and Fr*) (Maths)**	Physics and Chemistry (Maths)**	Biology (Maths)**	Physics, Chemistry, Biology, Science (Maths)**
GENDER	Male	Female	Female	Male	Male

The exploratory sample for the main empirical stage of this research was finally composed of five Secondary science teachers, belonging to three different schools (one state-funded, two independent) located in Spain and England[11]. Throughout this document, the participants are referred to by pseudonyms[12], the first letter of which corresponds to the school

[10] I had the opportunity to attend some lessons of a Year-10 Physics teacher who invited me so that I could have a different perspective on how the teachers at School-C work. He declined to be part of my research formally, though.

[11] I would like to comment on what happened with David, the teacher of the second school from Cambridge that accepted my invitation. I had a meeting with this teacher and the head of the science department of the school, where we specified a starting date and a schedule for my observations. David only had availability for my research one day per week. I attended six lessons with him, but we could not find time for the interview during my stay, nor afterwards. Once my observations with him were transcribed, I realised there was a huge difference between the amount, quality and depth of data gathered with David and with the other participants; so, after much considering, I decided to exclude him from my analysis.

[12] The justification behind this change in names is protecting participant anonymity. Gender has been maintained.

where they work. Thus, Alba and Adrian are teachers from School A; Becca and Barney, from School B; and Christian, from School C. Each participant constitutes a unique case influenced by their past experiences, their characteristics, their perspectives of teaching and learning, and the context in which they work. I hoped this would increase my opportunities to identify patterns and contrasts for the cases (Miles & Huberman, 1994). Table 3.5 provides a summary of some relevant details of the participants.

3.6. Methods for data collection

Any research design must be methodologically coherent; that it, there must be congruence between the research paradigm, the research questions, the sample, the methodology, the methods for data collection and the analytical procedures (Morse *et al.,* 2002). The choice of methodology does not inexorably prescribe the choice of a specific research method; however, there are some methodological strategies and some methods that tend to work particularly well together. Concerning case study designs, it is common to find researchers who suggest the use of a range of sources for collecting information (Hetherington, 2013; Yin, 1993), since the number of relevant variables greatly exceeds the number of cases (Yin, 1994). Despite employing more than one method for data gathering, researchers in the multi-methods approach must still restrict to a single research paradigm (Mingers & Brocklesby, 1997).

In addition to methodology, another element that guides the choice of data collection methods is the research topic. In my case, the focus of interest is teachers' PCK of scientific explanation. Many scholars agree that no single instrument can capture the multidimensional nature of PCK (Aydeniz & Kirbulut, 2014; Park & Chen, 2012; Van Driel *et al.,* 2002), since it requires collecting information about "what teachers know, what they believe, what they do, and the reasons for their actions" (Baxter & Lederman, 2006, p.158). 'What teachers do' pointed to observing the practice of teaching in contextualised situations (Ball *et al.,* 2005). However, as Shulman (1987) and Kagan (1990) defend, PCK is partly an internal construct, and therefore, it cannot be observed directly; it is necessary to ask teachers to articulate their knowledge. Hence, to obtain data on teachers' PCK, beliefs, and conscious experience with scientific explanations, interviews seemed to be the most reasonable method to complement observations. The following sections present a justification for my choice of both data collection methods, along with a discussion on some issues concerning their implementation.

3.6.1. Observations

Pring (2000) says that, in many situations, when we want to know something, we just go to where the phenomenon of interest is happening and *look*. To this statement, Simpson and

Tuson (1995) would reply that *observing* is more than *just looking.* Observing requires an active and purposive recording of information along different dimensions, and a subsequent analysis and interpretation of what has been observed. This makes observation an intensive way of gathering information, but also one of the most versatile research methods.

There is a multitude of observational techniques. My first step after deciding to use this method was, then, to select the one that best suited my research. Appropriateness had to be determined by my research questions, the nature of the phenomena to be observed and the context in which the observations would be conducted (Simpson & Tuson, 1995). Researchers under the so-called 'structured' or 'systematic observations' employ well-defined and explicit knowledge of the events to be observed (Guthrie, 2003), which allows the measurement of predefined variables. To do so, they use schedules and measurement tools (Creswell, 2013). The exploratory character of my case study, located in an interpretive and qualitative paradigm, pointed to a less structured approach. Researchers who conduct unstructured observations do not use pre-determined schedules, but record and document as many varied data as possible, to identify categories and themes that might be relevant to their research questions (Gibson & Brown, 2009).

During my observations in School-A, I followed a quite unstructured approach. I took open-ended notes of everything I suspected could help me outline some preliminary categories related to teachers' PCK of scientific explanation. For my second round, in School-B, I had already developed an operational definition of 'scientific explanation', and my observations began to be more systematic, without becoming fully structured. I mainly focused on four aspects: i) the classroom context (including the physical, material, and human resources, the room configuration, the classroom routines); ii) the interactions between the teacher and students (including the types of strategies used, the discursive moves, classroom management techniques, groupings, student/student interactions, and classroom roles); iii) the assessment activities, methods and models; and iv) any explicit allusion to scientific explanation or to aspects related to the nature of science and to the conceptualisation of science-as-practice. The tentative codes for this stage had been built up according to the results of my pilot study (§A.2), the PCK model of Magnusson *et al*. (1999), and literature on scientific explanation (§A.3). I followed this same procedure in School-C.

I spent five/six weeks observing each teacher of my study. My choice for the duration of the observation period was based on a trade-off between i) the time necessary to familiarise with the context, ii) the time necessary to gain the participants' trust, and iii) making sure that there were enough opportunities for they to design episodes dedicated to constructing scientific explanations, on the one hand; and, on the other hand, the time required to transcribe, translate, analyse and interpret all the data. That is, although in exploratory case studies "the longer the researcher is able to spend 'on site', the better" (Denscombe, 2010, p.208), I did not overlook the fact that qualitative analysis of observational data can be a challenging, time-consuming, and demanding process (Gall *et al.,* 1996). All sessions were audiotaped with a Samsung® MP4 device –placed on the teacher's desk, or on my table, if the teacher was moving around. Fieldnotes were taken during the lessons.

Since I wanted to capture "the detail, the subtleties, the complexity and the interconnectedness" within the observational settings, without too much "disruption so as to be able to see things as they normally occur" (Denscombe, 2010, p.206), I acted as a non-participant observer during my whole fieldwork stage. I was aware that my presence could generate some stress in the people involved, though. To minimise the impact on students, the first day I introduced both myself and my project. In addition to providing some personal and academic details, I made it clear that I was there just to observe, not to participate in class activities or to assess them. I also tried to make them grasp that my research focus was the teacher, not the students, so they could act as naturally as possible[13]. All the teachers got used to my presence early and easily. I told them in advance which lessons I intended to attend. My relationship with all the participants was very positive and sometimes even close, but they strictly respected my role a mere observer within the classroom.

3.6.2. Interviews

Any method for data gathering provides a limited picture of complex phenomena like PCK (Van Driel, *et al.*, 2002; Park & Chen, 2012). Observing my participants in action gave me access to some aspects of how they implement the construction of scientific explanations in the classroom. But to understand their knowledge and beliefs about this epistemic practice, as well as the intentions behind their actions (Peker & Dolan, 2014), an additional method was required;

[13] Students from schools B and C were accustomed to visitors, according to their teachers; therefore, the observations in these classrooms were quite smooth. In fact, while observing in School-C, it was common that parents of prospective students attend some of the science lessons. In School-A, things were somewhat different. In some groups, my presence seemed to alter some students' behaviour. In the youngest age groups, this was translated into attempts to attract my attention. Many children tried to talk to me and some even tried to gain my trust. The oldest ones also modified their behaviour in a more negative way; at least, this is what Alba, Adrian, and Álvaro complained about. After the second week -perhaps discouraged by my lack of response- they began to relax, becoming more comfortable with my presence and not being distracted by it. Towards the middle of the observation cycle and onwards, the lessons run without incidents.

interviews seemed the best candidate. From the beginning, the selected teachers knew about my intention to interview them, and all had explicitly consented.

Given the exploratory, qualitative and interpretive nature of my research project, it seemed reasonable to make use of what Kvale (1983) names 'qualitative research interview'. According to Kvale, the purpose of qualitative interviews is to "gather descriptions of the life-world of the interviewee with respect to interpretation of the meaning of the described phenomena" (p.174). Seidman (1998) uses the term 'in-depth interviews' to refer to those interviews whose final goal is not "to test hypothesis and not to evaluate", but to "(understand) the experience of other people and the meaning they make of (it)" (p.3). In both cases, the respondents need to be given the opportunity to reconstruct their experience within the topic under study. To meet this goal, the interview must be conducted under a low degree of structure, making a priority use of open questions, and focusing on specific situations of the participants' world. The so-called 'semi-structured interviews' matches perfectly with these requirements, and so, this is the technique I chose with my participants.

In semi-structured interviews, the researcher has a pre-conceived list of topics to be addressed and some questions to be answered; but these are flexible and can be adapted as the interview progresses to help the respondent develop her ideas, and to keep the discussion open (Denscombe, 2010; Howell, 2013). This way of proceeding i) favours the uniqueness of each individual interview (Fylan 2005), allowing the researcher to delve into the personal differences between the participants, their inconsistencies and contradictions (Barriball & While, 1994); and ii) maximises the elicitation of concepts that might be pertinent to the research. The latter has special relevance for the case at hand, since, as I noted, PCK is often held unconsciously (Kagan, 1990) and teachers might need some help to put into words their thoughts and beliefs.

The topics and questions I included in my interview schedule came from different sources (King, 2014): the research literature about the topic, my personal knowledge and experience about the phenomenon under study, and some preliminary work –including my pilot observations and some informal conversations. These broad areas were subsequently broken down into more manageable questions, delineating a framework that did increase the comprehensiveness of my data and simplified its subsequent analysis (Cohen *et al.*, 2007). The interview schedules are presented in Appendix A.4.

All the participants were interviewed individually. Interviews took between 30 and 50 minutes. I followed the guidelines suggested by Weiss (1994) and Kvale (1996); that is, I framed the interview with a brief introduction, used a variety of types of questions, and often asked participants to provide examples or clarify their words. All interviews were audio-recorded with my Samsung® digital recorder and transcribed verbatim.

In addition to the interviews agreed in advance, my involvement in school life allowed me to debrief informally with teachers after lessons, and to have informal conversations during the lunchtime; these conversations –which were recorded in my fieldnotes– helped me to strengthen my relationship with the participants, besides giving me the opportunity to depict a more coherent image of their personalities and their ideas on both research-related and unrelated topics.

3.7. Methods for data analysis

Every research study entails decisions about the data analysis process, which may influence, and be influenced by, the rest of the design. In order to increase credibility, it is necessary to make explicit these decisions once they are made, to create an account as complete and detailed as possible about how the analysis was finally conducted (Boeije, 2002). This is especially relevant for studies under EPR2 (Taber, 2013), since its interpretative nature requires such an intimate involvement from the researcher (§3.3) that she might be accused of too subjective interpretations (Barreto-Espino, 2010).

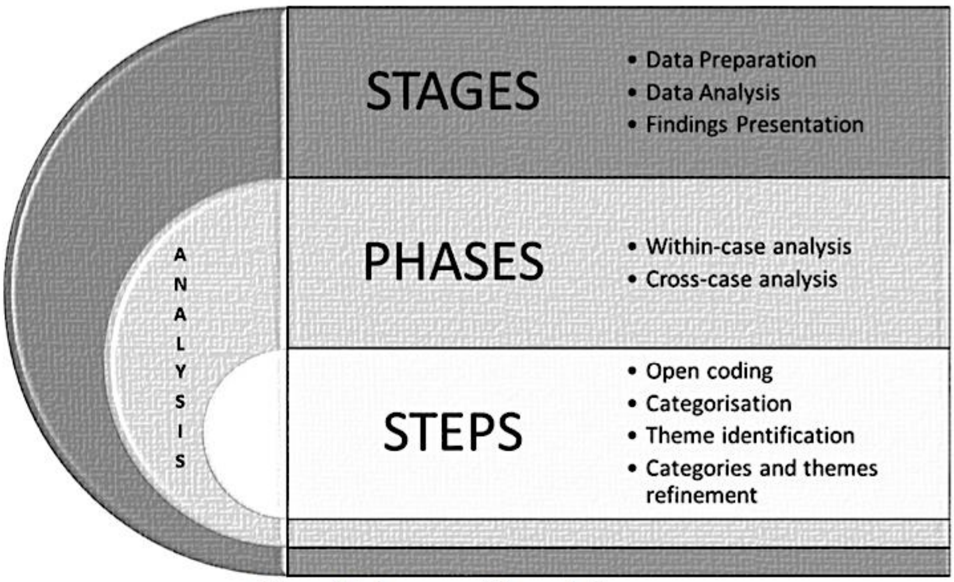

Figure 3.7. Sequence of the analysis process.

In exploratory case studies like mine, the analysis of data is a process of sense-making aimed at providing an exhaustive and holistic description of the cases (Brock, 2017; Merriam, 1998). Although there is a huge assortment of ways of analysing qualitative data collected under this methodological umbrella, they usually include some of the following stages (Lacey & Luff, 2001): i) preparation and familiarisation with the data; ii) analysis of the data. It includes coding, development of provisional categories, exploration of relationships between categories, identification of themes, and refinement of themes and categories; and finally, iii) Interpretation of the final themes and categories. This leads to the development of conclusions and their report to be incorporated into the pre-existing knowledge. In the next sections, I explain how all these stages –summarised in Figure 3.7– were conducted.

3.7.1. Data preparation

The analysis of the collected data began with a conscious preparation of them. Usually, immediately following an observed lesson, I listened to the recordings, to confirm it had been audiotaped without setbacks. I noted down some comments as I went through the data, to complement and check the impressions I had registered as fieldnotes during the session. I did the same with the recorded interviews. As suggested by Stake (1995), the research questions were constantly in my mind during this process.

The second step in the preparation of data was to transcribe the observed lessons and interviews. I personally transcribed all the recordings without using any software, to gain a greater understanding of the participants and the data. Something I had in mind during the transcription process is that, like any other step of the research design, it is not neutral, but reflects "(the) researcher's conceptualisation of a phenomenon, purposes for the research, theories guiding the data collection and analysis, and programmatic goals" (Green *et al.,* 1997, p.172). One decision I had to make was about the degree of naturalisation of teachers' discourse (Bucholtz, 2000). The kind of transcription I performed cannot be identified with any of the extremes proposed by Bucholtz. Thus, although to facilitate the analysis I literalised certain aspects of the participants' discourse (e.g., incorporating commas, full stops, and paragraphs depending on the length of their pauses), I tried to preserve some features of oral language, such as hesitations, stammering, non-concordant words, and speech errors. Another decision was about the content of the explanatory episodes selected for analysis. I decided to refine the original transcripts by leaving out some turns of speech which were not relevant to the phenomenon under discussion, such as those referred to classroom organisation or behaviour management. Dialogue disruptions are represented with ellipses in brackets (…).

Once the transcriptions were made and carefully reviewed for accuracy, I created a single document for each participant, which synthesised chronologically all the fieldwork data gathered from different sources (interviews, observations, and fieldnotes). This first document would serve as the basis for my case profiles. Although no formal coding took place as data were being prepared, it would be misleading to suggest that no conceptualisation at all occurred, since I always had in mind my research questions and many ideas from the existing literature.

I elaborated a second document for each teacher, which contained all the episodes of explanation construction that I could identify during my period of observation. Considering the long-accepted connection between why-questions and explanations (Hempel & Oppenheim, 1948; Tuomela, 1980), to be qualified as an explanatory episode, the transcribed fragment had to contain a why-question, and/or any form of the verb 'explain'. The second document such produced was the basis for my analysis of teachers' PCK of scientific explanation, with the episodes being used as coding units[14]. Their elaboration required a deep word-by-word scrutiny of my transcriptions (Kelle, 2007). The selected episodes ranged from a couple of sentences (e.g., E#4-Be) to quite large sequences of utterances (e.g., E#6-Ad). For each unit, I coded the participants' moves attempting to initiate, sustain, and/or develop the explanation. Episodes that were originally in Spanish were translated into English. I accomplished all the translation work. The whole process took 5-6 weeks of completion per teacher[15].

3.7.2. Within-case data analysis

The analysis of the collected data took place in two phases, one within cases and, the other, across cases. The corresponding findings are reported in Chapter 4 and Chapter 5, respectively. In this section, I explain how the within-case phase analysis was carried out.

The approach I adopted for analysis within cases was the constant comparative method (Glaser, 1965). As any other method of qualitative analysis, the purpose of the constant comparative method is to generate explicit categories which can help to provide an understanding of the data (Strauss & Corbin, 1998). As described above, before starting the coding process, I had elaborated two documents for each participant. One contained all the fieldwork data organised chronologically, and the other, the identified episodes of explanation seeking.

I conducted an open-coded line-by-line analysis for the first document of Adrian. This required fragmenting the data into manageable passages (Burton *et al*, 2014) and labelling each chunk with an adequate code. My purpose with this open coding was to identify features that might reflect Adrian's teaching practice and context. This process was guided by Bartholomew,

[14] The PCK documents produced for Adrian, Becca, and Christian are shown in Appendices A.5, A.6, and A.7, respectively.

[15] Data gathered from Álvaro, Annabelle and David were also transcribed, although they were not finally included in the sample to be analysed [§3.5].

Osborne and Ratcliffe's (2004) dimensions of effective practice to teach science (Figure 3.7.2.a). Another aspect to which I paid particular attention in Adrian's passages was assessment.

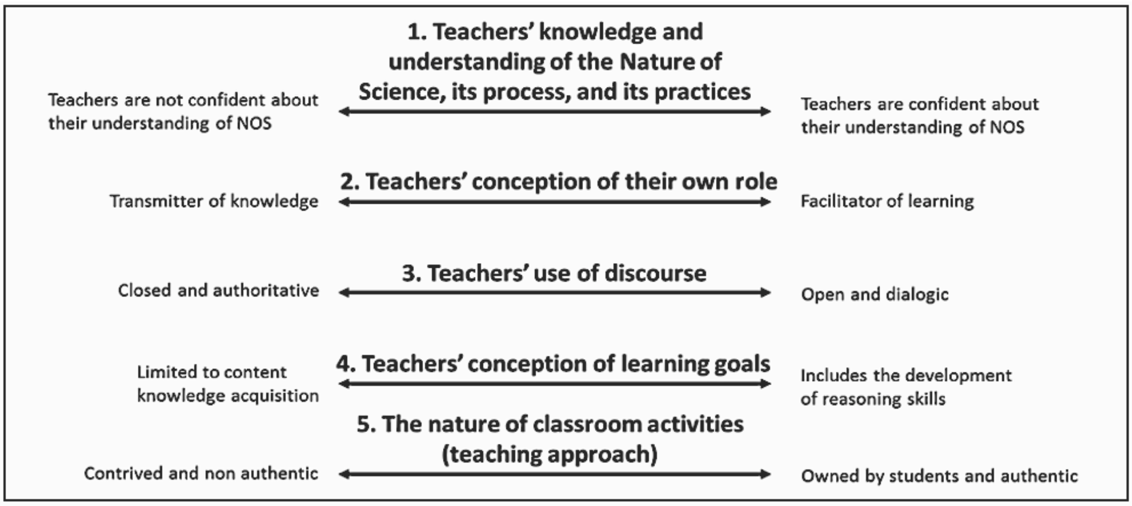

Figure 3.7.2.a) Bartholomew, Osborne and Ratcliffe's (2004) dimensions of effective practice to teach science.

Once I had coded the entire document, I started a process of intra-comparison. I compared coded instances of different parts of the transcription with others that had been similarly coded. With this, the consistency within the same participant was probed. I, then, followed a similar process with Alba, for whom new codes emerged. This time, I not only did compare and contrast codes within Alba's transcriptions, but also with the codes previously developed for Adrian. This allowed me to integrate codes under common broad headings, which served as the basis for the elaboration of Adrian' case description. I repeated this iterative process with all the participants, which resulted in the formulation of a coding framework that "span[ned] the data set but yet remain[ed] empirically grounded in the details of specific episodes" (Mcclain & Cobb, 2001, p.107).

The analysis of the document with the explanatory episodes was somewhat similar but much more thorough, since this time, the purpose was not to contextualise my study, but to find potential answers to my research questions. For me, the most complicated albeit illuminating part was the analysis of the Knowledge of Instructional Strategies (KIS), so that I detail it here by way of illustration. This analysis started with Becca's data. I decided to start with Becca because, at that point in my investigation, she was the participant I thought had the best-developed episodes of explanation construction, in comparison to Alba and Adrian. I explored Becca's case in depth to combine, divide and eliminate codes in order to generate categories of the instructional strategies she used. I then utilised these initial categories as lenses to examine the other sample teachers' cases, looking for confirming or disconfirming evidence for each, as well as for potential new categories.

Michaels and O´Connor (2016) maintain that teachers' interactions and actions targeted to get students involved in a certain practice have a major influence on the level of reasoning these manifest. I found, then, pertinent to build up some tentative codes for Becca's interactions and actions to engage students in building explanations. I drew upon several analytical frames, including Mortimer and Scott (2003), the SEDA framework (Henessy *et al.,* 2016), and Kaartinen and Kumpulainen (2002). Mortimer and Scott 's framework is based on five intertwined aspects around the role of the teacher to construct meanings in the classroom. These aspects are grouped in terms of intentions (excluded from my analysis because of the type of data collected), communicative approaches and actions. Within action, they include 'type of activities proposed', 'interaction patterns', and teacher's 'communicative acts' or 'discourse moves.'

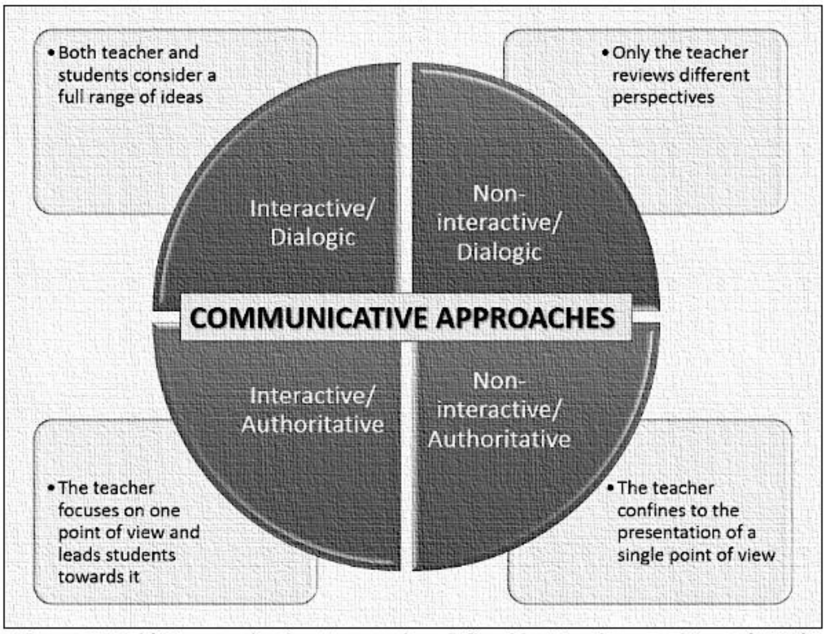

Figure 3.7.2.b) Communicative Approaches defined by Mortimer and Scott (2003).

Mortimer and Scott combine two dimensions –level of student interaction, and diversity of perspectives– to create four different categories to characterise the communicative approaches present in any episode of classroom talk. These four categories are (Figure 3.7.2.b): i) Interactive/ Dialogic: when both teacher and students consider a full range of ideas; ii) Noninteractive/ Dialogic: when only the teacher reviews and summarises different perspectives, either by simply enumerating them or by exploring similarities and differences (Scott *et al.,* 2006); iii) Interactive/Authoritative: when the teacher focuses on one specific point of view and leads students through questions and answers towards its consolidation; and iv) Noninteractive/Authoritative: when the teacher confines herself to the presentation of a single point of view. I used these as coding categories to analyse how Becca orchestrated the talk of her lessons, in interacting with students, to develop scientific explanations.

Communicative acts are segments of discourse that are intended to produce a specific effect on the person who receives them (Maybury, 1991). Taken together, these acts may capture the goal structure of a dialogic exchange (Carletta *et al.,* 1997). To analyse teachers' communicative acts, I developed an analytical framework which combined the SEDA framework (Hennessy *et al.*, 2016) and the work of Kaartinen and Kumpulainen (2002). The SEDA framework proposes 33 codes grouped into eight clusters for teachers' discourse moves. Some aspects of the clustering proposed by Hennessy and her team seemed too convoluted and unwieldy in practice, so I decided to nuance and complement them with the analytical framework proposed by Kaartinen and Kumpulainen, much more concise and applicable to the process of explanation construction in the classroom. All this was complemented with some ideas adapted from the Tutor Dialogue Move Coding Scheme, developed by Lehman *et al.* (2012).

Taking these three frames as starting points, I devised a coding scheme that acted as an analytical framework for making sense of the students-teacher dialogic interactions that took place in the explanatory episodes that I observed. Some of the codes were deductive. Most of them, though, emerged inductively on interaction with the data as the transcripts were analysed. The same procedure was carried out with each participant's data. I came up with similar or new codes compared with those present in the existing literature or induced from Becca's data. A comprehensive definition of the 115 discursive moves I employed in coding all the transcripts is shown in Table A.3.4. The codes were then grouped into seven clusters or categories, namely: Initiating, Continuing, Extending, Referring Back, Replying, Commenting/Reinforcing, and Concluding moves. For analysing the type of activities proposed and for teachers' interaction patterns, I did not follow any initial framework, but all the categories emerged from the tentative inductive codes.

3.7.3. Cross-case data analysis. Theme identification

For the phase of cross-examination, the categories that had emerged during the within-case analysis stage were compared to identify common patterns (themes) across participants. This analysis technique is known as thematic analysis (Braun & Clarke, 2006). As with the term 'case', it is relevant to define what is meant by 'theme' in this context to understand the results that one can expect from this type of analysis. According to DeSantis and Ugarriza (2000), "[a] theme is an abstract entity that brings meaning and identity to a recurrent experience and its variant manifestations. As such, a theme captures and unifies the nature or basis of the experience into a meaningful whole" (p.362). From a more methodological rather than ontological perspective, Braun and Clarke (2006) claim that a theme must "capture something important about the data in relation to the research question, and represents some level of patterned response or meaning within the data set" (p.82).

In my multiple case study, themes were identified in an inductive or 'bottom up' way (Bogdan & Biklen, 1998), so that they were strongly linked to data themselves (Patton, 1990). Thus, through a new round of constant comparative analysis –in which I read through each participant's documents several times, noting differences and similarities between them– I created a cluster of categories with its particular codes and definitions that applied to all the teachers under study. This cluster of categories permitted the identification and elaboration of several themes of interest concerning teachers' knowledge, ideas and practices about how to implement the practice of scientific explanation building in the classroom. These themes were then refined and reported in the form of five assertions, which were directly related to my research questions (see Table 3.7.3). Taken together, these assertions tell a coherent story about my data (Nowell *et al.,* 2017; Attride-Stirling, 2001).

Table 3.7.3. Emerging assertions and research questions.

RESEARCH QUESTION	ASSERTION
Q1a. What ideas, knowledge and beliefs do teachers hold about scientific explanation?	***Assertion #1.*** Teachers display a multiplicity of meanings for 'explanation' ***Assertion #2.*** Despite being identified as an essential scientific practice, explanation construction - as I have operationalised it- is rarely purposively integrated into instruction
Q1b. What instructional practices do science teachers engage in during science lessons to support students in constructing scientific explanations?	***Assertion #2.*** Despite being identified as an essential scientific practice, explanation construction - as I have operationalised it- is rarely purposely integrated into instruction ***Assertion #3.*** Teachers rarely display specific instructional sequences to promote the construction of scientific explanations. However, they use some strategies to interact and guide students in explanatory episodes
Q1c. How do teachers assess students' attempts to construct explanations?	***Assertion #4.*** Teachers do not possess specific assessment models for the construction of explanations
Q2. What do teachers perceive to be the fostering and/or hindering conditions for the teaching of scientific explanation production in the classroom?	***Assertion #5.*** Teachers perceive some inhibitors and some fostering conditions for designing environments in which explanation-production plays a significant role

CHAPTER 4. CASE PROFILES

4.1. Overview

As I reported in Chapter 3 (§3.7), the analysis of empirical data was undertaken within and across cases. Within-case analysis involved approaching each participant as an all-inclusive case in itself, in which as many aspects of contextual variables as possible were taken into account (Merriam, 1988). The findings of the within-case analysis consist in the elicitation of three of the five components of the PCK of Scientific Explanation for each teacher; these findings are summarised and discussed in this chapter. Cross-case analysis involved comparisons between cases and conceptualisations of various themes that seemed to transcend the individual instances. The findings of the cross-case analysis are reported and discussed in Chapter 5.

I am aware that, for researchers adopting case studies, communicating the findings in a succinct, clear and convincing manner may be a troublesome task, due to the complex nature of this methodology (Baxter & Jack, 2008). To facilitate this process, Chapter 4 has been divided into different sections, each of which corresponds to one participant; they are herein referred to as Adrian, Becca, and Christian, respectively[16].

Each case profile is introduced with a description of the context within which the phenomenon under study was observed. When presenting the case study methodology, I mentioned how relevant it is to take the context under consideration to make sense of the results of qualitative inquiry (Yin, 2009). Then, to fully understand my assertions about teachers' PCK of scientific explanation, this description is required. It includes a brief portrayal of some aspects of the educational system in both Spain and England. Following this, attention is turned to each of the three selected school, highlighting factors like school type, size, and characteristics of the students. I also comment about the participants' main features and experiences related to the purposes of this study, such as their education and training (both in science and science teaching) and their teaching and professional practice. Finally, I present a comprehensive profile for each participant's PCK of scientific explanation in terms of their

[16] The reader may have noted that data were collected from five participants: Alba, Adrian, Barney, Becca, and Christian. In order to meet the word limit requirements for the University of Cambridge's PhD dissertations, it was necessary to either edit the cases or select only some of them. Given that the logic of case study requires in-depth examination of unique instances, and reporting with thick description, it was decided that three of the cases should be reported in full –those which offered the maximum variation for cross-case analysis. The other two cases (corresponding to Alba and Barney) have been included as appendices (A.8 and A.9, respectively), so they are also available to the reader.

Orientations Towards Science (OTS), the Instructional Strategies and learning tasks adopted (KIS), and the Assessment demands made in their classes (KAs) (Magnusson *et al.,* 1999). I use verbatim data excerpts to illustrate the story of each participant and to support my interpretation of their practice-specific PCK.

4.2. Study's Context: A brief overview of the Spanish educational system

According to the last published PISA report[17], Spain ranks number 30 (out of 70) in scientific literacy for Secondary students, while the United Kingdom obtained the 15th position. Although it is beyond the scope of this thesis to make any claim to try to explain this difference in the OECD ranking, I can affirm that the Spanish and English education systems differ markedly in both organisational and curricular aspects.

Article 27 of the Spanish Constitution recognises education as a right to everyone (Courts, 1978). Since the Constitution became effective, a series of laws and educational reforms have been coming one after another, with quite a different scope and impact. The most significant reform took place in 1990, with the entry into force of the Law of General Organisation of the Educational System (LOGSE), whose consequences can be seen today in terms of structure of the system, curriculum, school management and other aspects. This law was especially relevant for the development of Secondary Education (ESO) in Spain (Lorenzo, 1996).

AGE	SPAIN	ENGLAND
11-12	6ºEP	YEAR 7
12-13	1ºESO	YEAR 8
13-14	2ºESO	YEAR 9
14-15	3ºESO	YEAR 10
15-16	4ºESO	YEAR 11

Table 4.2. Equivalence of the Secondary stage years between Spanish and English system

One of the most innovative contributions of the 1990's reform was the extension of the basic compulsory education from 14 up to 16 years. This extension broke the gap between the minimum legal age to work (16) and the end of school, putting Spain in tune with other European school models. The structure of the Secondary stage proposed by the LOGSE is still maintained with few variations. This stage consists of four courses organised in two blocks (1º, 2º, and

[17] PISA report (OECD, 2018). https://www.oecd.org/pisa/pisa-2015-results-in-focus.pdf

3ºESO, on the one hand, and 4ºESO, on the other). Table 4.2. shows the equivalence between levels in Spain and England. To facilitate comparison, in this dissertation, I use English nomenclature.

The implementation of the LOGSE could not alleviate one of the main problems of education in Spain, though: the high rate of school failure. During the 1990s, the percentage of students who drop out of school before obtaining their diploma in basic education was over 30%, a rate that remained practically constant, with slight fluctuations, until 2009. Since then, this percentage has been decreasing, until reaching its current value of 18%. Despite the evident improvement, this value is still far from OECD's goal of 15%, which keeps Spain at the bottom in terms of school failure[18].

Concerned about these data, the different political parties composing the Spanish government have strived for applying a huge range of specific programs and actions, especially for Compulsory Secondary Education. The following chart (Figure 4.2.a) shows the evolution of Spanish legislation in education. At the time I write this thesis, the Law for the Improvement of Educational Quality (LOMCE) is the law in force, although its implementation throughout the Spanish territory has been highly problematic.

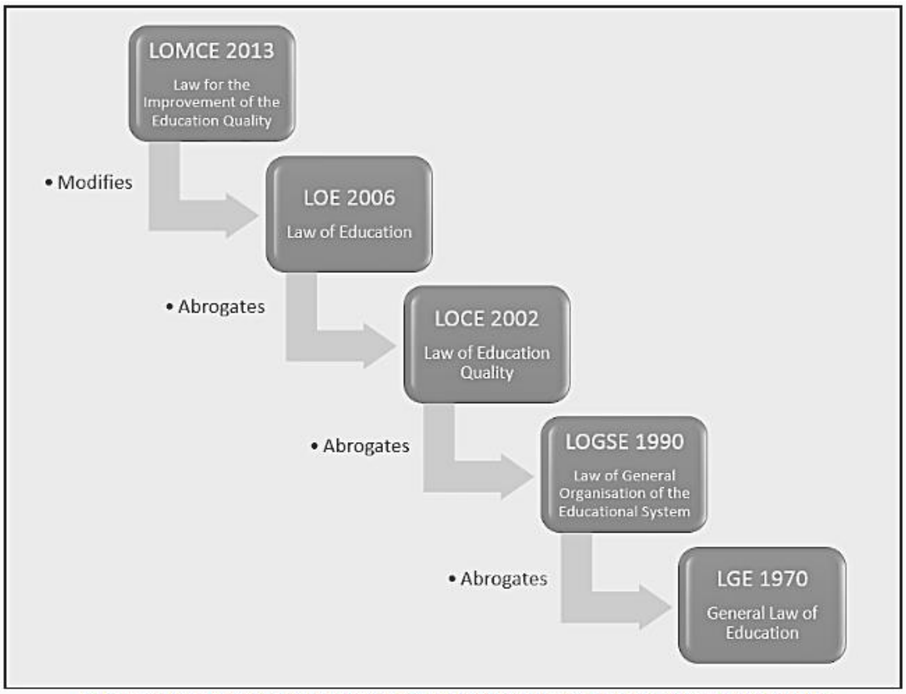

Figure 4.2.a) Main educational laws of the Spanish Legislative Framework

[18] Data provided by CCOO (2018). http://www.fe.ccoo.es/ce481b7bdf4baa40b9113155f2e94bbb000063.pdf

In addition to establishing measures to improve education quality, the Central Administration oversees the design of the compulsory National Curriculum. This includes the educational objectives, competencies, contents, standards and evaluable learning outcomes, and assessment criteria for every specific subject. Among the core subjects that the LOMCE sets forth for Secondary school students, we find Biology and Geology in the 1st year (Year 8), Physics and Chemistry in the 2nd year (Year 9), and both Biology and Geology, and Physics and Chemistry in the 3rd year (Year 10). In addition, students in their 4th year (Year 11) must choose two elective subjects from a group of four, including Biology and Geology, and Physics and Chemistry. It corresponds to the different Local Administrations to decide the number of hours scheduled for each subject.

The aforementioned Article 27 of the Spanish Constitution recognises the right of parents to choose a school for their children. There are three types of schools they can choose: state schools, publicly-funded independent schools (called 'concerted schools'), and independent schools, which differ on the type of ownership, the governing body, and the funding body (Figure 4.2.b). According to the Spanish Ministry of Education[19], 65.6% of students attend Secondary Education in state-funded schools. The remaining 34.4% is enrolled in private schools (either independent or concerted).

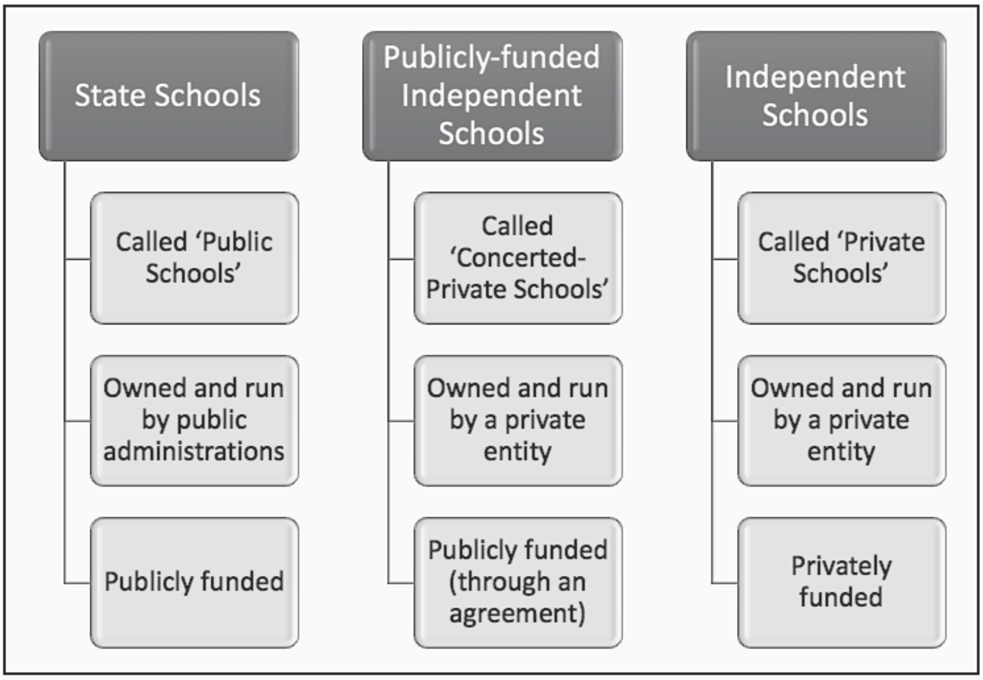

Figure 4.2.b) Types of school permitted by the Spanish legislative framework.

[19]http://estadisticas.mecd.gob.es/EducaDynPx/educabase/index.htm?type=pcaxisandpath=/Educacion/Alumnado/Matriculado/2017-2018RD/RGEsoandfile=pcaxisandl=s0

4.3. School-A

The first school selected for my case study is a state Secondary school located in a town near Madrid (Spain). The income *per capita* of the almost 20,0000 inhabitants of this town is below the Spanish national average (22,092€ vs. 25,950€)[20]. The body of students in School-A presents a heterogeneity of socio-economic profiles. In the informative meeting I had with the headmaster of School-A, he told me that more than half of his students come from disadvantaged families, while the ones with more economic resources choose the school because of its bilingual programme. Adrian, one of the participant teachers from the English-Spanish programme in this school, declared in his interview that "t*he high number of teachers (85) and students (1,200), together with the heterogeneity of the latter, is a challenge for all staff members, and teachers in particular*" (I-Ad)[21]. As detailed in Section 3.5, four teachers volunteered to participate in my research study (Adrian, Alba, Álvaro and Annabelle), but finally, only Adrian's case was included in the main text body of this dissertation, and Alba's case was included as an appendix (§A.8).

School-A belongs to a net of state-funded Secondary schools subscribed to a bilingual teaching programme run within the community of Madrid[22]. Due to this, Science subjects can be taught in Spanish, English, and/or French. To facilitate the process of teaching in a foreign language, School-A teachers are accompanied in some lessons by conversation assistants. These assistants do not possess any specific training and/or education in Science, and so, they do not focus on the content but on the formal and grammatical aspects of students' verbal interventions. They have the authority to assess some aspects of students' learning.

Interestingly (and contrary to what happens with the French department), there is no collaboration between the Science and English departments. Adrian admits this is "*an added difficulty that should be solved*". But he recognises this is an exception, since there is usually a "*high degree of coordination between all the teaching staff"* (I-Ad). Both Adrian and Alba noted in their respective interviews that the degree of intradepartmental organisation is remarkable, which translates into coordinated agendas and common assessment criteria and tests. Alba added that "*the willingness of colleagues to help each other facilitates the creation of a pleasant work environment and enables a constant development of new ideas*" (I-Al).

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[20] Data taken from the website https://datosmacro.expansion.com/mercado-laboral/renta/espana/municipios.

[21] Teachers form School-A were interviewed in Spanish. I accomplished the translation work into English.

[22] Consejería de Educación (2010). https://comunidadbilingue.educa2.madrid.org/web/educamadrid/principal/files/986e1ea9-605b-4368-928f-d8747acdc949/ProgramasEBilingue_Madrid_Publicacion_web.pdf?t=1372677483977.

4.3.1. Adrian's case

ADRIAN	YEAR 9	YEAR 11
CLASSES	3 hours/week/group	3 hours/week
No. OF GROUPS	4 (2 En., 2 Sp.)	1 (Sp)
No. STUDENTS/GROUP	32, 29, 31, 24	32
No. OBSERVED LESSONS/GROUP	10, 10, 12, 11	9
TOPICS	Units and conversion factors; forces (gravity, friction force, electrical force)	Describing motion
EXPLANATORY EPISODES	23	6

Table 4.3.1. Details about Adrian's observed lessons.

4.3.1.1. Description of classroom context and teaching

Even before deciding what to study after High-School, Adrian was clear that he wanted to become a teacher. He chose a University Degree in Chemistry as the first step toward this goal. Since he finished his degree, he devoted his efforts to pass the exam that enables teachers to get a permanent place in the Spanish public education system[23]. The first time Adrian took the test, he could not get a mark high enough to obtain a permanent position, but he entered the system as a supply teacher. For two years, he moved through different Secondary schools with this status. In 2016, he tried again, and this time he did achieve a teaching staff position in School-A. Since then, he has been in the same school, teaching Physics and Chemistry in several groups in Years 9 and 11, both in Spanish and English.

The three characteristics that Adrian considers best define him as a teacher are tolerance, patience, and willingness to help students. Regarding his conceptualisation of learning, Adrian says he has a "*constructivist conception* of *knowledge*" (I-Ad). He believes that students' previous ideas should be taken as a starting point for designing and monitoring the progress of the class. During the observed lessons, he often solicited students' ideas before introducing a new concept or revealing an answer.

[23] In Spain, all teachers who exercise in state schools are civil servants of the Spanish State. To be eligible for one of these vacancies, it is a necessary condition to have a teaching diploma (for Secondary school teachers, either a certificate of pedagogical training or a master's degree (equivalent to the British PGCE)). Once this requirement is met, candidates can apply for a public examination. The first phase of this public examination consists of a content-knowledge test, with both a theoretical and a practical part. If the candidate succeeds in this first phase, she will have to defend a didactic unit (previously planned) in front of a panel of examiners. As a complement to these tests, prospective public teachers must accredit a series of academic and professional merits. Although it is not necessary, teaching experience is also valued.

Despite his reported conception of learning, Adrian's way of speaking did not rigorously reflect these beliefs. On many occasions throughout our interview, he referred to the teacher as a "*transmitter of new knowledge*" (I-Ad). His practice was also strongly teacher-centred. In Adrian's lessons, students' role is limited to answering questions posed by him, solving (closed) mathematical problems and closed questions autonomously, and then share their answers on the board. Adrian finds keeping students busy with these kinds of tasks to be enough for them to learn.

Adrian said to be aware that the students are not "*the real protagonist*" of his classes, although he thinks "*they should be"* (I-Ad). During our conversations, Adrian repeatedly expressed his ideal of changing the kind of tasks pupils performed in school. He would like them to engage in more hands-on activities, as opposed to reading, listening, and writing. He opined the school is "*too theoretical*". He intends to relieve this situation by conducting skill-building activities during lab sessions, with students engaging in manipulative activities (e.g., assembling experimental devices), following procedures (e.g., collecting data on springs' behaviour) and practising some intellectual skills (e.g., transforming table data into graphical representations). However, he knows these activities are worksheet-driven, fairly standardised, scarce, and repetitive rather than open-ended.

When I asked Adrian what his main goals were as a science teacher, he responded: i) making learning attractive to students; ii) help students appreciate the importance that science and technology have in society; and iii) help students learn everything they need to function as citizens. One way to achieve these goals, says Adrian, is to "*spread enthusiasm for both scientific knowledge and knowledge in general*" (I-Ad). Adrian's practice reflects a narrower objective that he also mentioned when answering another question during our interview, which is to provide "*an understanding of the established subject matter knowledge"* to his students. More concretely, he stated that he wanted students "*know some laws, in the form of mathematical equations that reflect relationships between magnitudes"* (I-Ad).

Adrian sees himself as the character who must guide students to acquire this *established* knowledge, for which he recognises that he "*invest(s) a considerable effort*" (I-Ad). When I asked him to specify what this effort consists of, Adrian described the typical scheme of one of his lessons:

> *"I always pose one or several open-ended questions to introduce the topic. Based on students' answers, I try to redirect the search toward new questions. Once we find a point of agreement or a question that we are not able*

> *to solve together, I introduce some theoretical content, with the corresponding explanation, to help them comprehend the unsolved questions. Once the theoretical content has been understood, I pose some quantitative questions, insisting on the properties we are studying, the units... it's a way of putting into practice the new content. We finish by reiterating the questions I raised at the beginning of the session."* (I-Ad)

The structure here described corresponds with what I observed during my stay in Madrid. The main difference is that, despite sometimes Adrian indeed introducing a topic through guided open questions, the most common opening was by students reading some PowerPoint slides out loud, to which he added explications, term clarifications, and examples.

In large part, Adrian's instruction was aimed to make explicit and to modify students' alternative ideas. Generally, he used questions to drive the students through a reasoning process, until they come to a contradiction. Once the necessary concepts had been introduced and understood –and any potential misconceptions, eliminated– Adrian would write the mathematical equation that relates them. After reviewing the units in which each magnitude is measured and giving examples for students to become familiar with the formulae, he introduced some activities of direct application.

Adrian believes that the interaction between teacher and students may enhance their understanding of the topics. Consequently, he encourages them to participate and not to be afraid of interrupting an explication to expose their doubts. Despite this explicit invitation, Adrian's students rarely asked questions, and they did not usually speak unless directly addressed. This could be because the students perceive Adrian as a serious and tough teacher with whom it is difficult to negotiate. Some aspects of Adrian's teaching and way of talking contributed to reinforce him as the only authority in the classroom. Some students confessed to me in an informal way that they had the feeling that Adrian could reprimand them for saying something in an inappropriate moment ('*He is a bit scary*'). Certainly, one of Adrian's main concerns seems to be to maintain discipline, within a climate of cordiality and respect.

> *"That's not the way you should talk to me, ok? So be really careful with that. May it be the last time you do that. Is that clear? Before talking, raise your hand. And after that, be polite, as I am when I talk to you. The thing is, I will not repeat, if you didn't hear me, it is because you were talking, because you are all always talking, more than you should."* (Y9.O19-Ad)

In an informal conversation, Adrian conceded that little variety in participation might be, in part, his fault, because as he had so many students, he didn't know everyone's name yet; then, he always addressed and encouraged the same people. Adrian claimed also to be aware of the limitations of this format of didactic teaching in which the teacher and not the students initiates practically all form of discourse in the classroom, but he does not believe he has the necessary means to alleviate this situation.

In School-A, it is the science department who decides what content will be taught at each level, always within the limits established by the National Curriculum. Adrian recognises that what the department judges most interesting to teach and to assess does not always coincide with what is relevant to him; however, *"as it is a team decision, (he) respect(s) i*t" (I-Ad). Once the department has discriminated the content, each teacher develops their own material for the lessons. In Adrian's case, for each topic he prepares a PowerPoint presentation that includes theoretical explanations, explicative diagrams, and problems to be solved by the students. Students are given a paper copy of this presentation.

Adrian confessed he would like to assess each student's learning with respect to his/her starting point. But, as this starting point is "*very difficult to determine*" (I-Ad), he opts for standardising the assessment criteria. For the final grade not to depend only on an exam, he uses a system of continuous evaluation, that requires an assortment of assessment instruments. This system is agreed upon by the science department. Thus, both the specific weight given to each item assessed and the exam format (including the type and number of questions) is common to all teachers of a subject for the same level. In Year 9 and Year 10, the written exam represents 60% of the total grade for the term, increasing this percentage to 70% in Year 11. The questions included in the tests are predominantly memory-based and quantitative; that is, they are problems to be solved numerically. Adrian believes that students do not usually have difficulties when it comes to understanding concepts but at the time of applying them, because this depends on their "*mathematical skills*" (I-Ad). That is why he insists on practising the "*quantitative questions*", as he calls them, on worksheets. The rest of the grade in Adrian's subjects is obtained from classwork and lab work, which is assessed from oral presentations, voluntary participation in the class activities, end-of-topic tests and lab reports. The students are aware of the percentages attributed to each element within this assessment system.

4.3.1.2. Adrian's PCK of Scientific Explanation. Introduction

Now that Adrian has been introduced, along with his targets as a science teacher, the instructional strategies he incorporates to promote learning, and his assessment methods, I can focus on the epistemic practice of scientific explanation. In the following sections, I present Adrian's knowledge of the role of explanation in science and science education (OTS) (§2.6). I also analyse thoroughly the instructional strategies used to help students perform the construction of explanations (KIS), his ideas about the dimensions of explanation building that are worth assessing (KAs), and, finally, the models Adrian uses for assessing student' performance (KAs). A summary of all these PCK components is detailed in Table 4.3.1.2.a. Despite being aware that the line between these components is not clear-cut (Baxter & Lederman, 2006; Fernández-Balboa & Stiehl, 1995), I have separated them for analytical reasons. To offer a deeper insight into the kind of episodes in which I base my analysis of Adrian's PCK, in Table 4.3.1.2. b, I include the transcription of a particular episode. I have chosen what I deem to be the most representative episode of how Adrian address scientific explanation in classroom.

<table>
<tr><th colspan="4">ADRIAN</th></tr>
<tr><th colspan="4">Orientation Toward Science (OTS)</th></tr>
<tr><td>Knowledge/beliefs about the goals of science</td><td>Knowledge/beliefs about science teaching and learning</td><td>Teaching practice</td><td>Knowledge/beliefs about Scientific explanation</td></tr>
<tr><td>· Science as knowledge
· Science helps us understand the world</td><td>· Self-defined as constructivist
· Talks of in terms of 'knowledge transmission'
· Recognised objectives: 1) Making science attractive; 2) Highlighting the importance of science for society; 3) Developing citizenship; and 4) Providing an understanding of subject matter</td><td>·Teacher-centred (high control of the classroom discourse)
· Content-focused
· Lack of opportunities to engage in authentic disciplinary practices
· Low rate of student participation</td><td>· Conflates explanation and argumentation
· Assortment of meanings for the verb 'explain' (Explications and Justifications)
· Not well-defined conceptualisation of scientific explanation</td></tr>
<tr><th colspan="4">Knowledge of Instructional Strategies (KIS)</th></tr>
<tr><td>Communicative approaches</td><td>Activities</td><td>Language devices</td><td>Interaction patterns</td></tr>
<tr><td>·Interactive/Authoritative (22 out of 27)</td><td>· Oral construction (Interaction teacher-students)
· No activities whose goal is to construct the explanation.</td><td>· Questions
· Requests/Invitations
· Corrections
· Repetitions
· References
· Changes/Constrictions in direction</td><td>· IRF</td></tr>
<tr><th colspan="4">Knowledge of Assessment (KAs)</th></tr>
<tr><td colspan="2">Dimensions to Assess</td><td colspan="2">Methods</td></tr>
<tr><td colspan="2">· Content acquisition
· Students' participation in class activities
· Lab work, presentations</td><td colspan="2">· No specific model/instrument to assess students' ability to construct explanations
· Informal assessment</td></tr>
</table>

Table 4.3.1.2.a) Summary of Adrian's PCK of Scientific Explanation.

Table 4.3.1.2.b) Vignette #1. Example of explanatory episode in Adrian's observed lessons

TEACHER	*ADRIAN*
VIGNETTE/EPISODE/OBSERVATION	***V#1 / E#24 / Y11.O1-Ad***
TOPIC	***Law of falling bodies***
Ad.- The slides tells us that all bodies fall with the same acceleration, independently of their mass. That is, a feather must fall at the same speed as a stone. Is that true in real life, or not? *Ss.-No.* *Ad.- And what do you think it changes, being this a Galileo's statement?* *S1.- The weight.* *Ad.- Isn't the weight the same as the mass, in the end?* *S2.- Yes.* *[Silence]* *Ad.- Aren't they always the same?* *S3.- Yes.* *Ad.- If the mass does not influence, by multiplying it by g, the weight does not have to be the determining factor.* *S2.- Can you repeat the question?* *Ad.- Yes. If all bodies fall with the same acceleration, which is independent of their mass,* ***why do we think that a stone and a feather do not fall with the same speed?*** *S4.- Because one takes less.* *Ad.- That's the same thing I'm asking.* *S5.- The time.* *Ad.- It's not the time ...* *S6.- The resistance.* *Ad.- Let's see, tell us.* *S6.- That the feather offers resistance.* *Ad.- Let's see, let's do a test, with the feather being a sheet, and the stone being a paper ball. Look. Would you say that these two folios have approximately the same weigh?* *Ss.- Yes (...).* *Ad.- With these two folios that have the same mass, I make a ball with one, and I leave the other as it is. If you observe the fall, it does not imply the same final velocity. So, the ball falls well before. And do you think the mass is the same?* *Ss.- Yes.* *Ad.- Then, if the mass is the same and they fall at different speeds, does the mass have any influence?* *Ss.- No.* *Ad.- No. In this case, what determines the difference between one case and another is, as you said, the force of friction, right? In the cases we are analysing, it is assumed that the bodies do not have friction. If there were no friction, as the mass is the same, the acceleration of gravity would also be, and, consequently, the two would fall at exactly the same speed. What happens is that this is an ideal theoretical framework. And we know that practical reality is slightly different. But that does not mean that this is not true. What it means is that we are changing the conditions. In any case, we are saying that the mass is a factor that is not at all influential in terms of the speed of free fall, okay? All right.*	

4.3.1.3. Orientation Towards Science (OTS): Adrian's knowledge and beliefs about Scientific Explanation

As we saw in Chapter 2 (§2.6), the potentially most influential element of teachers' Pedagogical Content Knowledge is their Orientation Towards Science (OTS), since it acts like a filter through which teachers view and interpret teaching and learning (Kagan, 1992), shaping other aspects of their PCK as decisions are made on the spot (Magnusson *et al.,* 1999). In this section, I portray Adrian's OTS in terms of (a) his view of science as a discipline; (b) the goals and purposes he ascribes to his classroom activities; and (c) his interpretation of the concept 'explanation'. My first research question (Q1a) brings together these different aspects.

Since producing explanations to make sense of the world is one of the ultimate objectives of scientists, teachers' understanding of scientific explanations might be related to their general understanding of science as a discipline. Keeping in mind this potential connection, in our interview, I asked Adrian what science is for him. He answered that science is "*a body of knowledge about the dynamics in our world, which enables us to interpret what happens around us*" (I-Ad). When asked to elucidate scientists' objectives, Adrian remarks that they devote a high percentage of their time to "*bibliographical consultation, that is to say, to read and to synthesise what is read*" (I-Ad). Besides, he thinks that scientists "*also accomplish experiments with the purpose of drawing conclusions*", although he does not specify what types of conclusions they intend to achieve.

Adrian admits that, in his lessons, he never makes explicit reference to how scientists work or what their objectives are, *"which might contribute [his students] to conceive science as a product, absolutely depersonalised*" (I-Ad). In Adrian's classes, there is a significant absence of practices aimed at promoting learners' high order thinking skills. On the contrary, the type of activities he proposed were dominated by low cognitive demanding questions that had a single, closed answer – "*The only thing we are doing now is applying the mathematical formulae of Hooke's Law. They are asking me what the value of the force is, and they give me the value of the constant and the mass*" (Y9.O10-Ad)– which contributed to students 'doing the lesson' rather than 'doing science' (Jiménez-Aleixandre *et al.*, 2000). This lack of opportunities to participate in authentic disciplinary practices (Pareja, 2014), coupled with how Adrian presents and talks about science, might hinder students' formation of appropriate ideas about the Nature of Science and its functioning outside the classroom.

As detailed in his profile description, Adrian's teaching and assessment performance focus on the acquisition of content that previously "[*the department] has considered [they] must transmit to the students"* (I-Ad). When I asked him about practice-related objectives, such as learning how to produce explanations, Adrian acknowledged this is not a priority for him. However, it is "*something that [he] ha[s] in mind*", since "*there is a lot –and dangerous– pseudoscientific ideas that are being disseminated. Then, using this type of arguments and doing it in a way that is irrefutable would help eliminate this type of pseudoscience and ungrounded theories*" (I-Ad). Although in my question, I only alluded to explanations, in his answer, Adrian identifies both explanation and argumentation as the same practice. According to him, in this practice, it is not only important to employ language properly to express ones' ideas, but also to make use of scientific evidence fittingly. This is quite revealing, because it denotes some knowledge about the elements needed to construct an argument, in accordance to the CER framework (§2.5.4).

Despite his aspirational interest, Adrian does not teach and assess the practice of explanation (neither argumentation) explicitly and/or systematically; he mentioned that he lacks the necessary knowledge and resources for it. When asked to specify what these would be, Adrian expanded on a response in which he referred to these kinds of practices as *innovations* that are demanded of teachers in reform documents. He believes that to accomplish these *innovations*, teachers should be provided with more means, although he does not name them; he just notes that a more specific pre-service education is needed.

I observed 52 lessons from Adrian. On 28 occasions within these sessions, he launched a *why-question* or demanded *an explanation*. But to my dismay, after a preliminary analysis of the collected data, I (maybe quite hastily) concluded that none of these episodes corresponded to my research interest. That is; despite the word 'explanation' constantly appeared in Adrian's discourse, there were no cases in which Adrian requested his students to construct a complete scientific explanation for a natural phenomenon, neither in the classroom nor in the laboratory sessions.

In our interview, I interrogated Adrian about the possibility that students could construct scientific explanations, and he replied he usually asked them to do this, although less often than he would like to. I was puzzled by his answer, because I had witnessed no example I considered might be classified as such. Then, I invited Adrian to specify how he did it, and he said:

> *"Indeed, at the beginning of the lesson, when we propose the answers to the questions that open the introduction of the topics that we are dealing with. So, it is not something that I have as an objective (…); but I do have in mind that I want, and I wish, that they have the capacity of sufficient and correct expression to defend their arguments. And in this case, logically, arguments of scientific nature. So,* ***it's not just about explaining it well, but explaining it with facts that are scientifically objective****. So, I would say 'yes, I do it', and this either at the beginning of the sessions or when we answer to any of the theoretical,*

practical, quantitative or qualitative activities that we are working in class or in the laboratory." (I-Ad)

By analysing both this reply and the rest of the observational data in more detail, I concluded that Adrian gives the verb 'explain' a huge assortment of meanings, and that when he asks 'why', he is not always referring to the same thing. This opened new inquiry lines in my research. I re-analysed the 28 selected episodes, and this time I classified them according to the meaning with which the verb 'explain' was being used. Under this broader perspective, eight episodes seemed to fit, to a greater or lesser extent, within my characterisation of scientific explanations as an attempt to articulate scientific knowledge to understand why a phenomenon happens. All these eight episodes are examples of oral constructions led, guided and sustained by Adrian, with the students relegated to a fairly passive role.

Within the category 'scientific explanation', I found mostly causal explanations –in which Adrian seeks to identify what produces a phenomenon– and some anthropomorphic explanations –in which he attributes human agency to certain entities to explain their behaviour. Within those explanations classified as 'non-scientific explanations', there were: i) rich descriptions –consisting of detailed accounts of what is happening; ii) concept clarifications –interpretations of the meaning of a term; and iii) metacognitive explanations –elicitations of the reasoning path followed to find a solution to a problem. In all these cases, students must provide an *explication* of their ideas and/or findings to their colleagues and Adrian. There were also numerous examples of justificatory explanations –where students provided reasons to believe that something is the case. Finally, there is one episode I labelled as 'mathematical convention' –where what is sought are the norms or codes that justify a mathematical representation. Interestingly, in the interview, Adrian did not explicitly allude to any of these meanings, although he connected the ability to explain with the ability to express one's ideas, which could relate to the notion of 'explication'.

Table 4.3.1.3 shows some examples for the different meanings of 'explanation' I found in Adrian' teaching practice.

Table 4.3.1.3) Different meanings of 'explanation' found in Adrian's observed lessons.

TYPE OF EXPLANATION	EPISODES	*EXAMPLE*
SCIENTIFIC EXPLANATION	**Articulation of theoretical and background knowledge to make sense of a certain phenomenon through a process of reasoning**	
Causal	5; 8; 12; 13;15; 16; 18; 19; 20; 22 ;24	*Ad.- If I'm moving at a certain speed, whatever it is, but it's always the same, and someone comes from behind and pushes me, does my speed change?* *Ss.- Yes.* *Ad.- Because that is non-uniform.* ***Why has my speed changed? What have they done to me when they pushed me?*** ***S1.- Apply a force.*** *Ad.- They have applied a force to me. And, since I have a mass, applying a force is the same as granting me one ...* *S2.- Acceleration.* *Ad.- Acceleration, indeed!* (E#8; Y9.O21-Ad)
Anthropomorphic	10;	*Ad.- [T]here is fluid friction because it's difficult to separate particles from the fluid. (…) You can imagine that this particle of air is in this position [pointing]. If we go right here with a car, we are going to change their positions. So, changing the relative position of the air is why there is a force of friction, ok?* ***Because they don't want to change, and we are forcing them to change****. (…)* ***They are saying: 'I don't want to change'. So, I will apply a force in order to not to change. (…) That's a possible explanation for the force of friction.*** (E#10; Y9.O26-Ba)
NON-SCIENTIFIC EXPLANATIONS	**Explications and Justifications**	
Clarifying concepts	9; 11; 14	*Do you know the meaning of the word 'proportional'? Or could you give two properties that are proportional? I mean,* ***explain the concept using an example****.* (E#9; Y9.O24-Ad) *Ad.- difference between them?* ***Could you give me an explanation for the gravity? Or what do you think the gravity is?*** *Is it a force?* *S1.- Yes.* *Ad.- And how does it work? [silence] Does it repel us from the surface of the planet? Or does it attract us?* (E#14; Y9.O29-Ad)
Rich description	16; 27	*Ad.-* ***Could you explain what's happening here? What are we talking about?*** *We are talking about springs. There is a mass hanging from that spring. The thing is that this first mass is a fourth part of this one, or, what is the same, this can be considered four times the first one, ok? So, this one is heavier, of course. And because of being heavier, that's why this spring is longer, ok? So, there should be a relationship between the mass that is hanging and the length of the spring, ok? So, if we've put more mass, the spring should be longer.* (E#27; Y9.O7-Ad)

Table 4.3.1.3) Different meanings of 'explanation' found in Adrian's observed lessons.

TYPE OF EXPLANATION	EPISODES	*EXAMPLE*
NON-SCIENTIFIC EXPLANATION	**Explications and Justifications**	
Mathematical convention	26	*Ad.- Note that the dimensions of the angular velocity are* t^{-1}. ***Why does only time appear at this angular velocity? What did we say about the angular magnitudes not having dimensions?*** *What did we comment yesterday about it that surprised you a little bit?* *S1.- That they do not have dimensions.* *Ad.- We said that they do not have dimension.* ***Why don't they have dimensions?*** *S2.- Because they are dimensionless.* *Ad.- Okay, that's the same, but with another word. But why is it dimensionless, or why does it have no dimensions?* *S2.- Because the dimensions have to disappear when we do a calculation.* (E#26; Y11.O7-Ad)
Justificatory	2; 3; 4; 6; 7; 21; 23	*Ad.- Ok, the question is 'when do we say a body is rigid?' So, I want you to tell me if the first answer is correct or not,* ***and the reasons why you have made that decision****. Raise your hand before talking, please. (…).* *S1.- In the question, it says: when do we say an object body is rigid? And the answer says: when it deforms… but if it's rigid, it does not deform, so…* *Ad.- Ok, so, another example could be that if we are talking about this object, that you can imagine it is used as a hair band, if we apply a force, it changes its shape. If I stop [exerting] the force, it recovers its original position. So, what kind of material is this?* *S2.- Elastic material.* *Ad.- It's an elastic one. So, this definition is for elastic materials. So,* ***I want you to tell me that this is false just because it's the definition for an elastic material.*** *So, 'A' is not the correct answer.* (E#2; Y9.O1-Ad)
Metacognitive	1; 25	*Ad.-* ***Could you explain what you have done?*** *S1.- First, I do decimal notation.* *Ad.- Ok.* *S1.- Then, I apply the conversion factor.* *Ad.- Ok, how many steps are there between metres and cubic decimetres?* *S1.- One step.* *Ad.- Ok, you mean three zeros. (…) So, are you going to multiply by 1000 and divide by 1, or are you going to divide by 1000 and multiply by 1?* *S1.- Eh…, multiply by 1000 and divide by 1.* *Ad.- Ok. So that's your result. It is expressed in decimal notation.* (E#1; Y9.O1-Ad)

As can be inferred from the interview passage in which Adrian talks about explanation (pp. 73–74), and from the examples I use throughout this section, it does not seem clear that Adrian has a well-defined conceptualisation of what a scientific explanation is, in the sense used both in this thesis and in reform documents and reports (§2.5.4). His characterisation of explanation is diffuse, conflating it with argumentation, with being able to elaborate a response, and, on numerous occasions, with telling others why they believe something is the case.

Perhaps due to this polysemy, Adrian uses or requests explanations in the classroom with many variated purposes. Sometimes, the main goal achieved through the elaboration of the explanation is, indeed, to understand a phenomenon (e.g., E#16-Ad). But he also demanded explanations (*justifications*) for other purposes, including: i) Introducing a new concept/property (e.g., friction: E#21-Ad); ii) Consolidating a concept/law (e.g. inverse proportionality between mass and acceleration: E#6-Ad); and iii) Eliminating a misconception (e.g. plasticity vs. elasticity: E#2-Ad; weight vs. mass: E#14-Ad).

In all of Adrian's episodes, learners' contributions to the dialogue were quite brief; they said just a few words (e.g., E#4-Ad and E#8-Ad). Thus, although Adrian maintained a great deal of interaction with his students through questioning, the interventions of the latter were generally so short that they hardly allowed the development of deep ideas. Besides, the exchanges were nearly always between Adrian and one/two students who took turns speaking, so they were not authentic community practices. This makes it difficult for an episode to occur in which students elaborate an explanation with some depth. This way of working might justify why Adrian does not make explicit mention of the elaboration of explanation in science. That students become proficient in this practice is, then, an objective far from being fulfilled.

4.3.1.4. Adrian's Knowledge of Instructional Strategies (KIS)

One of the PCK aspects to consider is about the pedagogical strategies employed by teachers to integrate scientific explanation in the classroom. In this section, I present the set of strategies that Adrian used to construct explanations in conjunction with his students. In Chapter 3 (§3.7), I detailed the frameworks I drew upon to develop my codes for analysing the participants' interactions and actions used to engage students in this practice. For the sake of understanding the analysis conducted for the selected explanatory episodes, I show in different tables the codes for Adrian's communicative approaches (Table 4.3.1.4.a) and for Adrian's actions. Actions are divided, in turn, into 'types of activities carried out' (Table 4.3.1.4.b), 'discourse moves' (Table 4.3.1.4.c) and 'patterns of interaction' (Table 4.3.1.4.d). Each of these items is accompanied by fragments taken from the 28 episodes as illustration.

Mortimer and Scott (2003) combine two dimensions –level of student interaction and diversity of perspectives– to create four categories to characterise classroom talk (see Figure 3.7.2.b). In Table 4.3.1.4.a, I summarise the communicative approaches that Adrian used in the different explanatory episodes. The most common enacted approach by Adrian is Interactive/Authoritative. Twenty-two out of the 28 episodes are framed within this category. In Episode #23, for example, Adrian constrains the students to find the words that fill a gap in his discourse. Another enlightening episode is Number 2 (E#2-Ad), in which Adrian encourages a student to justify her answer. Although the pupil makes an argument in the form of a disjunctive syllogism, Adrian ends up revealing to the class the answer he had in mind since the beginning. He even tells the students he *wants* them to give that answer and no other, reinforcing his epistemic authority. In some Authoritative episodes (e.g., E#1-Ad), when one student says something that does not coincide with what Adrian expects or that is incorrect, he discards the answer and requests a new one, or simply rephrases and moves on. Sometimes, Adrian uses a particular tone of voice to show disagreement, and straightaway gives the answer he was thinking (e.g., E#11-Ad). Finally, when Adrian perceives the students are not following his speech, he opts to answer the questions himself (e.g., E#13-Ad).

In two episodes, the communicative approach taken by Adrian is Non-interactive/ Authoritative. In these occasions, Adrian does not explore any different perspectives, but just canonically accepted ideas. If Adrian frames questions during these episodes, these have a rhetorical character.

Finally, we can also find some, although scarce, examples of Dialogic approaches in Adrian's explanatory episodes; one Interactive and the other Non-interactive. In both cases, Adrian leaves open the possibility that the explanation developed is one among a set of potential ones. While in Episode #16, Adrian allows the students express their ideas without confirming or refuting them, in Episode #10, it is Adrian himself who proposes a possible explanation for the phenomenon of friction in fluids.

I have included an excerpt in this table which is qualified as 'non-classifiable' under this framework. On it, Adrian refers to one of the multiple meanings of the word 'explain' that he displays in his practice; however, I do not consider it an explanatory episode properly speaking, as neither the students, nor Adrian himself tries to produce an explanation, whatever the type.

Table 4.3.1.4.a) Adrian's communicative approach for the episodes on explanation.

COMMUNICATIVE APPROACH	EPISODES	EVIDENCE
Interactive/ Authoritative	1; 2; 3; 4; 6; 7; 8; 9; 11;13; 14; 15; 17; 18; 19; 20; 21; 22; 23; 24; 26; 27	*Ad.- What makes ice more desirable as a surface for this sport?* *S1.- Because it is more slippery.* *Ad.- It is more slippery**, which is the same as saying that ...*** *S2.- It is more slithery.* *Ad.- It is more slithery, **which is the same as saying that ...*** *S3.- That it has less irregularities.* *Ad.- That it has less irregularities, **which is the same as saying that ...*** *S3.- That there is less friction.* *Ad.- That there is less friction, **that there is less...*** *S4.- Friction force.* (E#23; Y9.O33-Ad)
Interactive/ Dialogic	16	*Ad.- Why does the pen stop and why does it start to come down? What is happening there for this phenomenon to occur?* *S1.- Weight.* *Ad.- Weight, which is the same as ...* *S2.- And also gravity.* *Ad.- And also the gravity. Well, are they the same, or are they two different things? Are they two forces that are acting simultaneously, or are they really the same and are we using two different ways to call them?* *S2.- They are different.* *Ad.- They are different ... **Well, let's see if that's the case or not.*** (E#16; Y9.O30-Ad)
Non-interactive/ Authoritative	5; 12	*Ad.- The moon has a lower gravity just because it is much smaller than our planet. And the acceleration of gravity is related to the mass of the body that we are considering.* (E#12; Y9.O28-Ad)
Non-interactive/ Dialogic	10	*Ad.- There is fluid friction because it's difficult to separate particles from the fluid. (…) You can imagine that this particle of air is in this position. if we go right here with a car, you are going to change their positions. so, changing the relative position of the air is why there is a force of friction, ok? because they don't want to change, and we are making them change. (…) They are saying: 'I don't want to change'. so, I will apply a force in order to not to change. (…) **That's a possible explanation for the force of friction**.* (E#10; Y9.O26-Ad)
Non-classifiable	25	*Ad.- Tomorrow, we will mark the exercise together, okay? I do not want you to be able to copy it from the photocopies, **but to be able to explain it.** To be able to, to some extent, tell the others how to solve it correctly.* (Y11.O7-Ad)

The four modalities of classroom talk that dominate Adrian's lessons were put into action through a series of specific activities. In Table 4.3.1.4.b, the kind of activities performed is shown. There are two elements worth highlighting regarding these activities. First, they all are based on an interaction between teacher and student. In other words, in no case do students work alone, in pairs or small groups; the production of the explanation always occurs in conjunction with Adrian himself. Secondly, constructing an explanation is never the final goal of the activity. The explanations are tools that Adrian utilises to achieve a curricular objective (as said in the previous section), either when solving an exercise, or as part of a didactic explication or an experiment.

Table 4.3.1.4.b) Types of activities present in Adrian's episodes on explanation.

TYPE OF ACTIVITY	EXAMPLES
Question checking/assessment (Teacher-student interaction)	*Ad.- What about 'B'?* *S1.- 'Does it have the same weight?' No, because on the moon, the weight is lower.* ***Ad.- And why is it lower? What is also changing?*** *S1.- Eh…, on the Earth surface, it's 9.8…* *Ad.- So, in order to calculate the weight, we are considering both mass and acceleration of gravity, ok? So, is the mass changing?* *S1.- No.* *Ad.- No, you told me that it is the same, all right.* ***Is the weight changing?*** ***S1.- Yes.*** ***Ad.- Why is it changing? Because the acceleration is changing.*** *Could you tell me both values?* *S1.- In the Earth surface, 9.8.* *Ad.- All right.* *S1.- And in the moon, 1.6.* *Ba- Ok.* (E#15; Y9.O29-Ad)
Didactic (Teacher-student interaction)	*Ad.- Have you heard about the magnetic levitation train? It is basically a train, making it much simpler than it really is, in which there is a magnet below and another magnet above. What happens when we have two magnets?* *Ss.- They repel [each other].* *Ad.- They repel. Well then, to a certain extent, this train, when it travels, does it without touching the tracks.* ***Why is it so fast? Because there is no friction force. Because there is no contact surface.*** *There is no frictional force with the tracks, but there is with the air*. (E#23; Y9.O33-Ad)
Thought experiment (Teacher-students interaction)	S1.- Can a submarine be an example of fluid friction? Ad.- Of course. It is the same as thinking about one of us swimming, ok? So, you are moving, and because of that motion, the water opposes to that motion. So, **you can imagine that what you are doing is moving the particles of the air or moving the particles of water.** If you need to move those particles, it is hard, and it means that you are going to spend some force in order to create those places to pass through. (E#16; Y11.O9-Al)
Modelled experiment (Teacher-students interaction)	*Ad.- If all bodies fall with the same acceleration, which is independent of their mass, why do we think that a stone and a feather do not fall with the same speed? (…)* *S4.- The resistance.* *Ad.- Let's see, tell us.* *S4.- That the feather offers resistance.* *Ad.-* ***Let's see, let's do a test, with the feather being a sheet, and the stone being a paper ball. Look****. Would you say that these two folios have approximately the same weigh?* *Ss.- Yes (...).* *Ad.- With these two sheets that have the same mass, I make a ball with one, and I leave the other as it is. If you observe the fall, it does not imply the same final velocity. So, the ball falls well before. And do you think the mass is the same?* *Ss.- Yes.* *Ad.- Then, if the mass is the same and they fall at different speeds, is the mass an influencing factor?* *Ss.- No.* (E#24; Y11.O1-Ad)

All the activities listed in the previous table are examples of oral constructions, in which Adrian leads and guides the reasoning process through a series of discourse moves. To gain an insight into the nature of these discursive interventions, I use the framework developed by Kaartinen and Kumpulainen (2002), combined with some of the categories proposed by the SEDA framework (Hennessy et al. 2016). In the selected episodes, I found evidence of all the categorised discourse moves; namely, Initiating, Extending, Continuing, Referring back, Replying, Commenting/Reinforcing, and Concluding moves.

To start the process of building an explanation, Adrian follows three different strategies. The first is to set out one or several questions to contextualise the problem and direct the students towards its solution. The questions may be targeted to an individual or the whole class, and they are usually simple and broad. For instance, Adrian often asks students something related to their previous experience or their daily lives (E#19-Ad). Questions may also refer to a concept already seen in class (E#8-Ad). And there are cases in which Adrian poses a question to elicit students' previous ideas about a certain topic (E#14-Ad). Another Initiating move is to explicitly draw students' attention toward what he wants to explain. In these cases, Adrian also refers to situations the students may have experienced or something they have already talked about in class (E#24-Ad). Finally, we find episodes in which Adrian invites student's reasoning (E#11-Ad).

Once an episode begins, Adrian deploys a huge variety of strategies so that students can continue inquiring about the ideas that come up in the flow of the discourse. His most typical option is to launch a series of triggering questions. The type of questions ranges from simple Yes/No questions to completely open questions, stopping over in multiple-choice questions. Some questions are addressed to a student Adrian is interacting with, others, to the whole class, and some are rhetorical. Sometimes, Adrian invites his pupils to continue with the development of the explanation through a direct request. We find requests of clarification, justification, examples, demonstrations, and opinions. These strategies may serve to facilitate the interpretation and integration of different ideas and pieces of information.

The interventions in which Adrian tries to impose his point of view on the students are quite revealing. I noted before that the Authoritative approach was the most frequent in Adrian's lessons. With this, I wanted to signify that in most dialectical exchanges, Adrian seems to have a privileged perspective he expects the students to acquire because it is the canonically accepted. This produces situations like Episode #20, where Adrian completes the students' sentences or gives prompts so that they can continue in a predetermined direction. I even observed an episode (E#1-Ad) in which Adrian indicates the class how they must solve the why-question. An alternative way of guiding the discourse towards a fixed direction is simply to ignore a student's intervention.

I conclude my analysis of Adrian's continuing moves with the one I find most interesting: the correction of flawed reasoning. In my operational definition of scientific explanation (§2.5.4), the reasoning component is the one that grants explanatory character to the whole construct. Numerous studies show that one of the most challenging aspects for students when building an explanation is to connect all the elements to obtain a logically coherent and scientifically complete account of the phenomenon under question (Russ *et al.,* 2008). That is why one of my initial interests was to see how participant teachers face students' difficulties when it comes to explaining phenomena. During my stage in Madrid, I noticed teachers did not explicitly work on this aspect, so the Knowledge about Students' component (§2.6) was removed from the pool of my research questions on PCK. When analysing Adrian's recordings, I realised that he was using some strategies whose purpose was indeed to solve a problem of reasoning. In two episodes, Adrian comments on a mistake made by a student. While in Episode #26, the pupil falls into the so-called labelling error (Taber & Watts, 2000), in Episode #24, we find a tautology (McNeill, 2011). In both cases, Adrian calls students' attention to the error but continues the exchange without much emphasis on it.

Under the label 'Extending moves' we find communicative acts that are used by Adrian to introduce new perspectives as a way to expand the explanation-building process. Sometimes he complements the students' contributions by adding some examples; on other occasions, Adrian ignores a student's response and changes direction. It is also usual that Adrian refers to a previous contribution –which could facilitate understanding– or utters some evaluations on the go to make students realise whether they are on the right track. Adrian usually marks an idea or shows his approval with a positive comment or by re-voicing the last contribution of a student in a confirming tone. In Table 4.3.1.4.c, there are examples for each of these moves.

Finally, Adrian displays many strategies to indicate to the students that they have reached the desired point; that is, Adrian uses numerous concluding moves in his explanatory episodes. Depending on the reasons why Adrian decided to request the explanation, he finishes the episode by providing the correct/predetermined answer, keeping the solution open, or changing the topic under discussion. Adrian also explicitly checks for students' understanding or lets them know they have given the correct answer, with an evaluative comment; this may be preceded by a repetition of what the student said.

Table 4.3.1.4.c) Discourse moves present in Adrian's episodes on explanation.

ADRIAN'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Initiating moves	Direct instruction (new problem)	*Ad.- I want you to tell me if the first answer is correct or not and* ***the reasons why you have made that decision****. Raise your hand before talking, please.* (E#2; Y9.O1-Ad)
	Factual Questioning	*Ad.-* ***Why does the pen stop and why does it start to come down? What is happening there for this phenomenon to occur?*** *S1.- Weight.* (E#16; Y9.O30-Ad)
	Refers to a prior contribution	*Ad.-* ***Why did you say that when we were talking about throwing a ball, it will stop sooner if you throw it in the beach, I mean, in the sand, than if you throw it in a skate park?*** *what's the different between both places?* *S1.- That in a skate park, the…* *Ad.- The surface…* *S1.- The surface is smooth, and in the beach, the surface is like the other way.* (E#20; Y9.O31_Ba)
	Casts/recalls students' attention	*Ad.-* ***Note that the dimensions of the angular velocity are t^{-1}.*** *Why does only time appear at this angular velocity? What did we say about the angular magnitudes not having dimensions?* ***What did we comment yesterday about it that surprised you a little bit?*** *S1.- That they do not have dimensions.* *Ad.- We said that they do not have dimension. Why don't they have dimensions?* (E#26; Y11.O7-Ad) ***Ad.- Have you ever heard about a magnetic train?*** ***S1.- Yes.*** ***Ad.-Why is it so fast?*** *S2.- Because it has only one friction, that is the air.* *Ba, Ok, and what is the one that is not happening?* *S1.- The floor.* *Ad.- The one with the floor, ok?* (E#20; Y9.O31-Ad)
	Invites elaboration /reasoning	*Ad.-* ***Let's think; what's the reason why when I throw the eraser, it stops?*** *It is because of the friction with the floor. Friction is a force applied opposite to the direction of the movement.* (E#5; Y9.O11-Ad) *Ad.-* ***Could you explain what you have done?*** *S1.-First, I do decimal notation.* *Ad.-Ok.* *S1.- Then, I apply the conversion factor.* *Ad.- Ok, how many steps are there between metres and cubic decimetres?* *S1.- One step*. (E#1; Y9.O1-Ad)

Table 4.3.1.4.c) Discourse moves present in Adrian's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy et al., 2016), and Kaartinen and Kumpulainen (2002)

ADRIAN'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Continuing moves	Closed Questioning	*Ad.- The slides tells us that all bodies fall with the same acceleration, independently of their mass. That is, a pen must fall at the same speed as a stone.* ***Is that true in real life, or not?*** ***SS.-No****.* *Ad.-* ***And what do you think it changes, being this a Galileo's statement?*** ***S1.- The weight.*** ***Ad.- Isn't the weight the same as the mass, in the end?*** ***S2.- Yes*** *[Silence]* ***Ad.- Aren't they always the same?*** ***S2.- Yes.*** *Ad.- If the mass does not influence, by multiplying it by g, the weight does not have to be the determining factor. (…)* ***Would you say that these two folios have approximately the same weigh?*** ***SS.- Yes (...).*** *Ad.- With these two sheets that have the same mass, I make a ball with one, and I leave the other as it is. If you observe the fall, it does not imply the same final velocity. So, the ball falls well before.* ***And do you think the mass is the same?*** ***SS.- Yes.*** ***Ad.- Then, if the mass is the same and they fall at different speeds, is the mass an influencing factor? No.*** *In this case, what determines the difference between one case, and another is, as you said, the force of friction, right? (*E#24; Y11.O1-Ad)
	Completes students' answers	Ad.- Why did you say that when we were talking about throwing a ball, it will stop sooner if you throw it in the beach, I mean, in the sand, than if you throw it in a skate park? What's the different between both places? **S1.- That in a skate park, the…** **Ad.- The surface…** **S1.- The surface** is smooth, and in the beach, the surface is like the other way. Ad.- Yes, so, when we are talking about the force of friction, is it higher in the skate park, or in the beach? S1.- In the beach. Ad.- And that's because…. S1.- **Because it has more…** **Ad.- The key word is 'irregularities', ok?** so, we can say that if there are more irregularities, it is easier to be stopped; it is, it will be stopped sooner. if there are no irregularities, it will be stopped later, ok? (E#21; Y9.O32-Ad)
	Asks for an opinion	*Ad.- "The acceleration that a force produces is inversely proportional to the mass of the body".* *S1.- I think it's true.* *Ad.- You think it's true, ok.* ***Any other opinion?*** (E#6; Y9.O19-Ad)

Table 4.3.1.4.c) Discourse moves present in Adrian's episodes on explanation.

<table>
<tr><th colspan="2">ADRIAN'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)</th><th>EXAMPLES</th></tr>
<tr><td rowspan="5">Continuing moves</td><td>Asks for clarification</td><td>Ad.- (…) Why do you think so? Tell me a reason why that's your answer.
S1.- I think that is ok because the acceleration is proportional to the mass.
Ad.- Proportional? Right there it's said: 'inversely proportional', it's not the same.
S1.- Inversely proportional.
Ad.- Ok, what does 'inversely proportional' mean? (E#6; Y9.O19-Ad)</td></tr>
<tr><td>Asks for examples</td><td>Ad.- Could you give an example of that? of two properties that increase together?
S1.- Eh…, the force and the acceleration.
Ad.- Ok, another one that is not the one here?
S1.- Eh… the mass and the acceleration?
Ad.- Well, let's try to forget about second law. Use another property. I mean, time, temperature, whatever, money, results, etc. (E#9; Y9.O24-Ad)</td></tr>
<tr><td>Asks for justification</td><td>Ad.- What about (c)?
S1.- I think is true.
Ad.- You think it's true. Could you read it and give us an explanation why?
S1.- With the same force, if we want to increase three times the acceleration, we should reduce the mass by a third.
Ad.- Ok, so? (E#7; Y9.O19-Ad).</td></tr>
<tr><td>Provides some prompts</td><td>Ad.- What makes ice more desirable as a surface for this sport?
S1.- Because it is more slippery.
Ad.- It is more slippery, which is the same as saying that ...
S2.- It is more slithery.
Ad.- It is more slithery, which is the same as saying that ...
S3.- That it has less irregularities.
Ad.- That it has less irregularities, which is the same as saying that ...
S3.- That there is less friction.
Ad.- That there is less friction, that there is less...
S4.- Friction force. (E#23; Y9.O33-Ad)</td></tr>
<tr><td>Asks for demonstration</td><td>S1.- That if you…, if the force you are applying to the object, if the object is, is, eh…, lighter, the acceleration, eh…, will be more…
Ad.- Ok, we agree about that. I mean, we know that it's easier to move a light object than a heavy one. But now, we have to demonstrate that information using numbers, ok? (E#7; Y9.O19-Ad)</td></tr>
</table>

Table 4.3.1.4.c) Discourse moves present in Adrian's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy et al., 2016), and Kaartinen and Kumpulainen (2002)

ADRIAN'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		**EXAMPLES**
Continuing moves	Invites elaboration /reasoning	*Ad.- If all bodies fall with the same acceleration, which is independent of their mass, why do we think that a stone and a feather do not fall with the same speed?* *S4.- Because one takes less.* *Ad.- That's the same thing I'm asking.* *S5.- The time…* *Ad.- It's not the time.* ***S6.- The resistance.*** ***Ad.- Let's see, tell us.*** ***S4.- That the feather offers resistance****.* (E#24; Y11.O1-Ad)
	Checks agreement	Ad.- Ok, but it is the definition for a kind of material…what kind of material is it for? S1.- Elastic materials. **Ad.- Do you agree? Yes or no? Raise your hand before giving me an answer.** S2.- I think it's for plastic materials. Ad.- So, what's the difference between plastic and an elastic material? S2.- That plastic [materials], when you apply a force on them, do not recover their original shape. And elastic materials do. (E#2; Y9.O3-Ad)
	Convergent Questioning (giving options)	*Ad.- Ok, how many steps are there between metres and cubic decimetres?* *S1.- One step.* *B.- Ok, you mean three zeros. (…)* ***So, are you going to multiply by 1000 and divide by 1, or are you going to divide by 1000 and multiply by 1?*** ***S1.- Eh…, multiply by 1000 and divide by 1.*** (E#1; Y9.O1-Ad)
	Corrects the reasoning	Ad.- We said that they do not have dimension. **Why don't they have dimensions?** **S2.- Because they are dimensionless.** **Ad.- Okay, that's the same, but with another word.** But why is it dimensionless, or why does it have no dimensions? (E#26; Y11.O7-Ad)

Table 4.3.1.4.c) Discourse moves present in Adrian's episodes on explanation.

ADRIAN'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Extending moves	Offers an additional answer	*S1.- In the question, it says: when do we say an object body is rigid? And the answer says: when it deforms… but if it's rigid, it does not deform, so…* ***Ad.- Ok, so, another example could be that if we are talking about this object, that you can imagine it is used as a hair band, if we apply a force, it changes its shape. If I stop [exerting] the force, it recovers its original position.*** (E#2; Y9.O1-Ad)
	Rhetorical questioning	*Ad.- Have you heard about the magnetic levitation train? It is basically a train, making it much simpler than it really is, in which there is a magnet below and another magnet above. What happens when we have two magnets?* *Ss.- They repel [each other].* *Ad.- They repel.* ***Well then, to a certain extent, this train, when it travels, does it without touching the tracks. Why is it so fast? Because there is no friction force. Because there is no contact surface. There is no frictional force with the tracks, but there is with the air***. (E#23; Y9.O33-Ad)
	Ignores an answer and changes direction	*Ad.- Ok. So, that's the gravity. We can say that the gravity is the force exerted by a planet, by a satellite, by a star, whatever, and it attracts the mass. So that's the gravity. What's the weight?* ***S2.- Something that you can…, eh…*** ***Ad.- So, for example, how often do you say 'my weight is 50kg'? Are you talking about your mass if you say that?*** *Ss.- Yes.* (E#14; Y9.O28-Ad)
Referring moves (Makes explicit links to:)	Prior contributions	*S1.- 'Does it have the same weight?' No, because on the moon, the weight is lower.* *Ad.- And why is it lower? What is also changing?* *S1.- Eh…, on the Earth surface, it's 9.8…* *Ad.- So, in order to calculate the weight, we are considering both mass and acceleration of gravity, ok? So, is the mass changing?* *S1.- No.* ***Ad.- No, you told me that it is the same, all right.*** (E#15; Y9.O29-Ad)
Replying moves	Responds to explicit questions	*Ad.- Why is it so fast? Because there is no friction force. Because there is no contact surface. There is no frictional force with the tracks, but there is with the air (...).* ***S1.- But what if it fails?*** ***Ad.- If it fails, it cannot advance. As if a normal train is damaged.*** ***S1.- Ok, but if, for example, one of the two magnets fail? It does like this [gesticulating] and you've been killed.*** ***Ad.- No, come on, don't be so dramatic! The only thing that happens is that the magnets are no longer separated and are resting on the track. And if it is stopped, it does not run. Nothing more happens than that.*** ***S1.- But do are not killed?*** ***Ad.- No, you are not killed****.* (E#24; Y9.O33-Ad)

Table 4.3.1.4.c) Discourse moves present in Adrian's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy et al., 2016), and Kaartinen and Kumpulainen (2002)

ADRIAN'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Commenting/ reinforcing moves	Explicitly shows agreement	*Ad.- **Ok, we agree about that. I mean, we know that it's easier to move a light object than a heavy one**. But now, we have to demonstrate that information using numbers, ok?* (E#7; Y9.O19-Ad)
	Repeats (adding some information)	*Ad.- [Consider you have] a football ball and a medicine ball of 3kg… have you ever played football with the second one?* *S1.- No.* *Ad.- No, why?* *S1.- Because it is very…* ***Ad.- Very heavy?*** ***S1.- Yes.*** ***Ad.- It's very heavy and very big.*** (E#4; Y9.O9-Ad)
Concluding moves	Provides correct/ predetermined answer	Ad.- It's an elastic one. So, this definition is for elastic materials. So, I want you to tell me that this is false just because it's the definition for an elastic material. So, 'A' is not the correct answer. (E#2; Y9.O1-Ad)
	Checks understanding	Ad.- The weight is going to change. Why? What is changing in order to say that the weight changes? [silence]. (…) What is the only property that you can change? The gravity of the planet. **Is that clear?** (E#13; Y9.O28-Ad)
	Repeats and makes a confirming comment	Ad.- Why has my speed changed? What have they done to me when they pushed me? S1.- Apply a force. Ad.- They have applied a force to me. And, since I have a mass, applying a force is the same as granting me one ... S2.- Acceleration. **Ad.- Acceleration, indeed!** (E#8; Y9.O21-Ad)
	Summarises (by rephrasing)	*Ad.- Is it easier to move a wardrove or a table right here, in this floor, or in the beach?* *S1.- Here.* *Ad.- Here it's easier; why?* *S2.- Because in the beach the surface is not smooth.* *Ad.- It's not smooth, there are more irregularities, it is the same. So, the properties, the quality of the surface always is going to influence the value of the friction, ok? **So, the more irregularities there are, the harder is going to move something.*** (E#19; Y9.O31-Ad)
	Does not give a final answer (but this will be given in the future)	*Ad.- Do you think that's because of the weight of because of the mass? Or because both of them?* *S1.- Both of them.* *Ad.- Ok, **that's a question we are going to try to answer in a few minutes**.* (E#4; Y9.O9-Ad)

Table 4.3.1.4.c) Discourse moves present in Adrian's episodes on explanation.

ADRIAN'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Concluding moves	Refers to the future	*Ad.- So, mass, kg; and weight, as it's a force, Newtons. So, they have different units, which means they are different properties.* ***They are not the same. But (…) they are connected, ok? And we are going to see that connection*** (E#11; Y9.O28)
	Refers to reality	*Ad.- In this case, what determines the difference between one case and another is, as you said, the force of friction, right? In the cases we are analysing, it is assumed that the bodies do not have friction. If there were no friction, as the mass is the same, the acceleration of gravity is also the same, and, consequently, the two would fall at exactly the same speed.* ***What happens is that this is an ideal theoretical framework. And we know that practical reality is a little different. But that does not mean that this is not true. What it means is that we are changing the conditions.*** *In any case, we are saying that the mass is a factor that is not at all influential in terms of the speed of free fall, okay? All right. (E#25; Y11.O1-Ad)*
	Changes of topic	*Ad.- You do know that the gravity on the moon is not the same as on Earth.* *S1.- Because there is no oxygen?* *Ad.- It has nothing to do with it, we'll see that. It is rather the other way around: there is less oxygen because there is less gravity, okay?* ***But well, in any case, without entering into the composition of the atmosphere,*** *we are saying that the force that we are considering, sometimes is called 'gravity' and other times is called 'weight'. (E#17; Y9.O30-Ad)*
	Adds some information	*Ad.- Have you ever heard about a magnetic train?* *S1.- Yes.* *Ad.-Why is it so fast?* *S2.- Because it has only one friction, that is the air.* *Ad.- Ok, and what is the one that is not happening?* *S1.- The floor.* *Ad.- The one with the floor, ok?* ***So, if you want to go faster, it is better not to have friction. If we want to be safer, it is better to have friction.*** (E#21; Y9.O31-Ad)
	Makes an evaluative comment	*Ad.- Ok. So that's your result. It is expressed in decimal notation. What about the scientific notation, is it correct, or not? What do you think?* ***Yes, it is correct.*** (E#1; Y9.O1-Ad)

To conclude my analysis of Adrian's instructional strategies, I show the two different patterns of interaction in which he engaged during his episodes of explanation production (Table 4.3.1.4.d).

Table 4.3.1.4.d) Adrian's patterns of interaction.

ADRIAN'S PATTERNS OF INTERACTION	EXAMPLES
IRF sequences	*Ad.- **Could you explain what you have done?*** *S1.-First, I do decimal notation.* *Ad.-Ok.* *S1.- Then, I apply the conversion factor.* *Ad.- Ok, how many steps are there between metres and cubic decimetres?* *S1.- One step.* *B.- Ok, you mean three zeros. (…) **So, are you going to multiply by 1000 and divide by 1, or are you going to divide by 1000 and multiply by 1?*** ***S1.- Eh…, multiply by 1000 and divide by 1.*** (E#1; Y9.O1-Ad)
Hesitations and pauses	Ad.- Why did you said that when we were talking about throwing a ball, it will stop sooner if you throw it in the beach, I mean, in the sand, then if you throw it in a skate park? What's the different between both places? **S1.- That in a skate park, the…** **Ad.- The surface…** **S1.- The surface** is smooth, and in the beach, the surface is like the other way. Ad.- Yes, so, when we are talking about the force of friction, is it higher in the skate park, or in the beach? S1.- In the beach. Ad.- And that's because…. S1.- **Because it has more…** **Ad.- The key word is 'irregularities', ok?** (E#22; Y9.O32-Ad)

Adrian usually orients his instruction to conversational turn-taking, where one speaker contributes at a time and where the gaps and overlaps are minimised (Sacks *et al*., 1974). The most repeated sequence in Adrian's episodes is the IRF. That is, the construction process typically starts with Adrian's questioning –which is called initiation (I), followed by one student's Response (R), and completed with some feedback move that demands a Follow up (F). The feedback stage may be explicit *"**Ok, good**. And will you give us the units of both of them"?* (E#11; Y9.O28-Ad). However, on most occasions, the evaluation is much subtle, since Adrian merely repeats what the student said. In these cases, a chain, in which one of the elements of the sequence is repeated, may begin.

Ad.- What makes ice more desirable as a surface for this sport?	I
*S1.- **Because it is more slippery**.*	R
***Ad.- It is more slippery**, which is the same as saying that ...*	F
*S2.- **It is more slithery.***	R
***Ad.- It is more slithery**, which is the same as saying that ...*	F
S3.- That it has less irregularities.	R
(E#24; Y9.O33-Ad)	

One last pattern of interaction that is repeated in Adrian's classes occurs when a student doubts or shows some indecision in her intervention and Adrian continues or completes her answer.

4.3.1.5. Adrian's Knowledge of Assessment (KAs)

In Chapter 2, I claimed that knowing what dimensions of science learning to assess, as well as how to assess them, was another relevant component of PCK, noted as KAs (§2.6). From the beginning, teachers' knowledge of assessment of scientific explanation was one of my main research interests. This interest was based on the idea, defended by many authors, that science teachers find it difficult to know how to assess non-conceptual content, such as students' understanding of NOS (Hanuscin *et al*., 2011) or their ability to participate in argumentative practices (Simon *et al*., 2006; Knight-Bardsley & McNeill, 2016). So, by analogy, I wanted to know whether my participants had specific models to assess the construction of explanations and how they put these models into practice if that was the case.

Portraying the KAs of a teacher requires the determination of the methods, instruments, approaches, and activities by which learning is assessed (Magnusson *et al.*, 1999). Methods of effective assessment may include informal, formative, and summative evaluations. In Adrian's observed episodes, it is not possible to find any evidence of the possession and/or use of any specific model or instrument to assess students' ability to construct explanations, or their understanding of this epistemic practice. In his interview, Adrian acknowledges that he does not properly assess this practice in the classroom since this is not one of the learning objectives that he deems as fundamental.

There are some exceptions to this assertion. In the interview, Adrian said that, in some exam questions and lab reports, the elaboration of an explanation was requested. He added that, in those situations, he assesses the *quality* of the given response. I had access to some of these exams and lab reports; in them, 'explanation' was always used as 'justification'. That is, Adrian requested his students not to construct an explanation for a phenomenon, but a justification for their answers. And what he really assessed was whether the given explanation matched a canonical one. It is difficult, then, to say what 'quality' means for him in this context.

As reported above, Adrian's assessment system does not consist exclusively in a final written test, but in a set of different instruments that are employed throughout the academic year. Between 20-30% of the final grade depends on classroom work. Thus, Adrian did formally assess students' contributions to classroom discussions. Namely, whether they contribute with ideas, respond to the questions posed, and engage in the proposed activities.

Moreover, although Adrian does not use any model to measure students' competence on this practice –that is, the production of explanations is not present in his summative assessment instruments, within the selected episodes– some informal assessment on students' performance takes place. Adrian tries to monitor whether they follow the reasoning process and assimilate the information. We have an example on Episode #6, where Adrian uses some questions to gauge whether a student knows the meaning of the concept 'inversely proportional' (E#6-Ad), or in Episode #15, where he uses a similar technique to check whether students grasp that 'mass' and 'weight' are not the same (E#15-Ad). More illuminating are the two cases in which Adrian corrects the reasoning errors of two students while they are trying to explain something; these are the already alluded tautology, in Episode #24, and labelling, in Episode #26 (§4.3.1.4). In both cases, to continue with the reasoning process, Adrian makes an evaluative comment, although he does not stop to analyse or explicate why these are mistakes.

4.3.1.6. Adrian's PCK of Scientific Explanation. Summary and discussion

Science is for Adrian a body of knowledge that leads to the interpretation and understanding of the world we inhabit. Adrian's characterisation of science as knowledge, instead of as a set of practices, coheres with his way of teaching science, with a clear predominance on conceptual content (and some problem-solving techniques). As Stroupe (2014) reports as common, then, students' experiences in Adrian's classes do not match those current educators and researchers' recommendations according to which science should be learnt as a practice. Kelly and Licona (2018), for instance, defend that achieving scientific literacy requires not only the acquisition of content knowledge but also the development of abilities to apply that knowledge, which entails certain mastery in a spectrum of disciplinary science practices. Duschl (2008) suggests that for students to achieve this mastery, learning environments should balance the articulation of three educational goals, which include i) the understanding of concepts and models (conceptual), ii) the understanding of their rationale and evidence (epistemic), and iii) the recognition of the procedures used by communities to generate, communicate and evaluate knowledge claims (social) (see Figure 2.3).

As the analysis of Adrian's lessons revealed, these are strongly structured and dominated by the teacher, who sets himself up as the only legitimate epistemic authority source. Bricker and Bell (2008) note that knowledge presented by authoritative sources is rarely questioned by the learners. This could be one of the reasons why Adrian's students so seldom contribute to the class with their ideas and questions. Ford (2008) claims that for students to effectively engage in science practices, teachers should avoid claiming exclusivity over epistemic authority and cede a part to the learners, instead. Stroupe (2014) calls those classrooms in which the teacher and the students divide and share the epistemic labour, and the latter may place their science ideas as central, 'ambitious classrooms'. Stroupe argues that this kind of environment enables legitimate participation in authentic disciplinary practices. Contrasting to this category, we find 'conservative classrooms', where the teacher "promot(es) the completion of curricular activities rather than sense-making, rarely tak(es) students' prior knowledge into account during lessons, seldom press(es) for evidence-based explanations, and treat(s) students' ideas as incongruent with canonical science" (Stroupe, 2014, p.488); this prevents students to become epistemic agents. As shown in his case profile, Adrian presents a conservative form of teaching in some aspects. Engaging students in learning science-as-practice could be challenging for Adrian because it is inconsistent with his well-established classroom and instructional norms.

We have also seen that Adrian's instruction is framed within an over-reliance on didactic transmission. He delivers and dictates notes to the students, who listen, copy, and answer when being questioned. The activities and questions proposed by Adrian are usually closed, with a single acceptable answer that may be directly obtained from the reading of the PowerPoint slides. Geddis *et al*. (1993) suggest that non-experienced teachers' predisposition to didactic approaches is motivated by a high degree of confidence in their subject-matter knowledge, combined with a naïve view of teaching and learning. Windschitl (2004) adds that these teachers focus almost entirely on presenting canonical science and on covering the compulsory curriculum; this results in an excessive provision of factual information, the repetition of algorithmic procedures for solving quantitative problems, and the prescription of closed practical activities. This description perfectly exemplifies Adrian's classes. It is also quite common that Adrian uses his didactic instruction to bring forth and address students' misconceptions, a connection that Aydin and Boz (2013) had already noticed.

Adrian proved to be remarkably skilled in this presentational style. The problem is that his students' role in shaping the learning experience is minimal; their contributions are limited to single words and/or short sentences that respond to a direct invitation from Adrian. Moreover, many pupils do not speak at all. Pimentel and McNeill (2013) analysed five secondary science teachers' practice. They found that whole-class discussions were mainly focused on factual information, and the teachers took on the role of knowledge providers. As it also happened with Adrian's students, Pimentel and McNeill showed that the participant students (n=116) provided very short contributions during the discussions and did not voluntarily delve on their reasoning. Since learning science-as-practice requires students to actively participate in discussions where they can use the discursive norms and the reasoning of science (Duschl *et al.*, 2007), it seems difficult that Adrian's pupils may reach this goal.

Focusing on the formulation of explanations, it can be said that neither in the interview nor in the numerous sessions observed, does Adrian explicitly mention this practice as something fundamental for science or science education. This could give us a first clue to understanding the lack of opportunities that Adrian provides so that his students may get involved in the production of scientific explanations. Twenty years ago, Coleman wrote:

> "(i)n many science classrooms, students spend most of their time either listening to teachers' explanations and lectures or reading explanations from texts (…). Rarely do they construct explanations for themselves. (…). Rarely do textbooks contain questions that require students to provide explanations longer than one sentence" (Coleman, 1998, p.390).

If we change the word 'textbook' in this fragment by 'PowerPoint slides', we would have a pretty accurate description of what can be found in Adrian's classes.

As mentioned in Section 4.3.1.4, Adrian's interaction patterns were mainly based on Initiation-Response-Follow up (IRF) sequences (Sinclair & Coulthard, 1992). Wells (1999) recognises that the IRF pattern reflects teachers' domineering epistemic authority. Other authors highlight that using IRF as the main classroom interaction pattern does not provide enough opportunities for students to fully participate in the classroom discourse, so that the teacher has much more speaking time than they do (Barnes, 2008; Cazden, 2001; Gutierrez, 1993). Mortimer and Scott (2003) claim that communicative approaches and actions are explicitly connected to teaching purposes. If the learning goal of a lesson is related to exploring and probing students' ideas, the IRF pattern may not be effective, and then more dialogic and interactive forms of discourse are required to meet this goal. Duschl and Osborne (2002) seem to go down this same path when they assert that the IRF sequences do not work well when the goal of instruction is to cultivate reasoning skills or *doing* science skills. This suggests that engaging in IRF sequences may not be the best strategy to use in contexts in which students are expected to learn to construct their own explanations. Thus, Adrian should include some other strategies to promote dialogic discourse, with all members of the community being, at least in principle, epistemically equal.

4.4. School-B

The second school of my study is a publicly-funded independent school (see Figure 4.2.b) located in a medium-size town (13,500 inhabitants) in the South of Spain. The income *per capita* of this town's residents is above the Spanish national average (28,996€ vs. 25,950€)[24].

In principle, concerted schools must accommodate all the entrance applications they receive. However, in case there is not enough places to all applicants, students are selected according to the so-called Admission Criteria. In School-B, these criteria include home proximity to the school, number of siblings enrolled in the centre, and the State qualification as large family.

School-B has a particular conceptualisation of education, which is reflected in its teaching methodology. Parents who request entry for their children are aware and value this. According to Ms Barros (headmistress of the school), this is the reason why most parents' profile follows a pattern. They usually possess a higher education degree, have a medium-high socioeconomic status, and are highly involved in their children's education. Ms Barros affirms this has an undeniable impact on the type of student and the school-family relationship. Indeed, one of the things that participant teachers highlighted about this school is that families "*play a key role in the school functioning*" (I-Ba). In our interview, Becca commented that at the beginning of the academic year, she communicates to the families "*how a subject is organised, what topics will be taught, and, even, what specific content will be covered. That way, the family –as well as the possible students' private supporting tutors– will know what they will work on in each term*" (I-Be). She tries to maintain this fluid relationship throughout the whole school year.

Another feature of this centre is its small number of students. During my fieldwork year, there were 347 students enrolled, with ages between 3 and 16, and distributed in a single group per grade level. When describing School-B, Becca focused on this small size: "*everybody knows each other (…). Many of the students join the school when they are three years-old*", which enables having "*a very personalised treatment with them*" (I-Be). This helps teachers to "*know the children who have difficulties*" –for whom they propose alternative activities– and those who have "*high abilities and need another motivation*" (I-Be) –for whom they also adapt the explanations and some of the classroom activities. Barney declares that he "*find(s) the size of*

[24] Data taken from the website https://datosmacro.expansion.com/mercado-laboral/ renta/ espana/ municipios

our school perfect and ideal to have that closeness, not only with students, but also with their families." (I-Ba).

4.4.1. Becca's case

BECCA	YEAR 9	YEAR 10	YEAR 11
CLASSES	3 hours/week	2 hours/week	3 hours/week
No. OF GROUPS	1	1	1
No. STUDENTS/GROUP	31	24	17 (elective subject)
No. OBSERVED LESSONS	11	9	12
TOPICS	The particulate nature of matter; pure and impure substances	Gas laws; chemical nomenclature	Properties and changes of materials; describing motion
EXPLANATORY EPISODES	5	6	8

Table 4.4.1. Details about Becca's observed lessons.

4.4.1.1. Description of classroom context and teaching

Becca self-defines as a teacher with a high vocation for education. While she was studying her degree in Chemistry, she used to teach private lessons. When she finished, she opened an after-school academy, where she offered tutoring for different subjects. After some years as a private tutor, she applied for a job in School-B; she has been working there for the last 12 years.

Becca is the only Physics and Chemistry teacher in the school, but she does not miss having a large Science Department because all the teachers "*consult each other and give pieces of advice*" (I-Be). This perception of support from her colleagues makes Becca "*not feel pressured when working*", so that she has no problems in introducing changes. This particularity, joined to the fact that she is *"a very flexible person",* favours a high degree of adaptation to each student, Becca says.

When planning her lessons, Becca has some targets in mind. Her main goal is *"to awaken students' curiosity*". Therefore, she proposes activities and working dynamics that contribute to students' *"happy attendance to school*", even if this means that some of the prescribed content is lost. Another goal is to make her students *"to think, to reason*" instead of simply *"read and memorise how to solve a problem*" (I-Be). This is something she tries to make students aware: *"I do not like that you learn things by heart, I've told you many times. Whoever knows the reasoning why it happens, she knows that they are inversely proportional magnitudes"* (Y10.O3-Be).

Regarding the content she does include in her classes, Becca says it is "*scant*" but *"purposely and thoroughly selected*" (I-Be) from the National curriculum, according to her objectives and experience. The first thing she considers is what has worked well in previous years. Secondly, she distributes the overlapping content from different subjects with the other teachers (e.g., 'Electricity', which appears in both the Science and the Technology curricula). Third, Becca conceives her syllabus as a long-term project. Since the Spanish law leaves this possibility open, Becca treats Year 9 and Year 10 as a single block, distributing the topics as she estimates best.

Becca does not see teaching as a simple affair where the selected content is dispensed to students by the teacher. For her, it is a challenging two-way process where students are at the centre of the stage. Becca is convinced that the most effective way to teach science is by involving the student in the process of knowledge construction: *"the student must be always active, either investigating by herself or doing things"* (I-Be). To achieve this, Becca aims to create an environment where everyone feels confident and motivated:

> *"My classes are usually a kind of shindig; there is a lot of noise, because the students feel free to talk, to participate… whenever they demonstrate that what they do is part of the activity, that is, that they are engaged with the work, it's good enough for me."* (I-Be)

This relevance of the student is reflected in a limited use of lecturing in Becca's lessons. In my recordings, it is very rare to find pieces in which Becca is simply expositing a topic. Instead, she prefers to provide students with guided opportunities to interact with each other; opportunities for they to think and investigate some problems and questions taken as starting points; and opportunities to share the knowledge constructed through dialogical exchanges. Besides, Becca is genuinely interested in students' experiential knowledge and previous ideas. She thinks her role is mainly *"to help them structure those ideas and make comparisons between different proposals, to challenge them to reach a consensus that seems coherent to the class as a whole and to each individual, so that they can understand*" (I-Al). In this negotiation process, Becca guides them by making questions and clarifying comments:

> *"I am going to ask you a question (…). You have to think, investigate, find out, or whatever you can, what the relationship between millilitres and grams is. You know how much water you have used, that is, how many millilitres, because it is what I have told you. But you don't know to how many grams they correspond. Once you know that, you can calculate the concentration as a percentage in mass." (Y9.O7-Be).*

Becca finds this way of teaching the most rewarding: *"you come up with thousand ideas, you perceive that the students respond... sometimes you have a noisy class and you get tired, your head hurts, you do not feel like doing anything... but you know you're achieving things, and that's encouraging*" (I-Al). Becca clarifies that her purpose of keeping her students happy at the school should not be confused with being indulgent, because she expects students to produce high-quality work.

Becca's beliefs about teaching and learning are reflected in her practice. Her instructional strategies rest on three pillars: project-based learning, cooperative learning, and problem-based learning. School-B encourages teachers to use a project-based approach in their lessons. Becca agrees that this is an excellent way "*to help students make connections between what they learn in the different subjects as well as in their daily lives, something usually hard for them*" (I-Be). This way of working is, according to her, something also difficult for teachers, who do not always know how to "*transmit that the things [they learn] must be seen in a global sense, as a whole*". This is specially challenging when they try to relate subjects that students see as very disparate. To avoid that, Becca works in collaboration with other teachers. For instance, a couple of years ago, she made a project with the Social Sciences teacher, in which they studied gunpowder. Becca thinks these collaborations are entertainment and pedagogical, but also challenging and time-consuming, and sometimes she comes to doubt that all her effort is worth it. First, because students do not always accompany that effort with their attitude:

> *"I want you to be clear that I find this, doing projects, much funnier, and very didactic, but, for me, it's an effort. Then, if you don't do your bit, I save that effort, I explain it on the board and assess it in a traditional way, (…), and that's all"* (Y9.O8-Be).

And second, because she is not sure that this learning methodology is the best for all the students.

> *"There are times when, even after having done things, they do not learn some things. For example, last year we made [a project on] soap, and I cannot guarantee you that if you ask the students, they know... there will probably be some who do not even know what a chemical reaction is."* (I-Be)

She adds that, for some students, it is hard to move from the security of "*the right answer in a textbook"* to participate in dialogues and open activities that require them to become independent learners. Despite these doubts, she continues working by projects because it fits with her main goal: *"(A)lthough they might have not learned [something], they do come happy to school. (…) That seems positive to me*." (I-Be)

Becca is also a strong advocate of cooperative learning. On the walls of her science classroom, there are posters about the need to 'share to learn'. Likewise, there are diagrams that summarise the different cooperative-work dynamics they can use. Becca is persuaded that collaborating with peers may contribute to "*make tasks more meaningful, lead to more fecund and concept-rich classroom dialogue, and improve students' understanding*" (I-Be). While being in her lessons, I every day witnessed some episode of group working, pair discussion, peer-review or more specific cooperative-work dynamics. For instance, in Year 9, Becca used both the so-called '1-2-4' and the 'experts' meeting' strategy. The occasions on which Becca's pupils worked individually were scarce. When they were asked to solve calculation problems, for example, they spontaneously did it in small groups. Generally, while the students were working to find the solution, she approached those individuals who find more difficulties and helped them to sort them out. Indeed, one of Becca's main concerns is that *"no student is left behind"* (I-Be). And if needed, she stops to clarify something to a single person while the others work – *"I think my past as a private tutor has given me a good background in this respect"* (I-Be).

Becca sometimes performs classroom demonstrations of scientific concepts (e.g., solubility, chemical reactions) and laws (e.g., Newton first Law). But generally, she prefers to prepare hands-on activities that enable her pupils experience the subject matter content of the course; this is what Svinicki and McKeachie (2011) call 'experiential learning'. During hands-on sessions, students did engage in manipulative activities (e.g., assembling distillation apparatus), followed procedures (e.g., collecting data on liquids behaviour) and practiced intellectual skills (e.g., transforming table data into graphical representations). All these activities' performances were done with materials that could be qualified as 'homemade'. In some responses, Becca commented about their lack of adequate facilities to perform this kind of work: *"we have some laboratory materials but, strictly speaking, we do not have a laboratory… let's say… professional*". Rather than seeing this as a reason to leave practices aside, Becca sees it as an opportunity to foster her creativity: "*I have to squeeze my imagination to get cheap things that are useful and didactic."* (I-Be). In the hands-on and lab sessions I attended, Becca embraced a problem-based approach. She asked the students to identify problems contextualised in real-world scenarios, to investigate these problems, and to develop some creative solution to them. During these episodes, Becca adopted the role of learning facilitator, guiding the process and promoting an inquiry-based environment.

Becca's assessment system is multifaceted: *"(I) try to assess everything"* (I-Be). This includes the knowledge acquired –in the form of written tests and oral presentations– and students' behaviour, participation, and submitted tasks. This has been facilitated by the incorporation of iPads® devices into the classroom, since they use an application and an online-working platform that records all the tasks for each student.

Becca uses rubrics to assess works, oral presentations, tasks, and exams; all the Secondary teachers use the same rubrics. Besides, she elaborates specific rubrics for the different projects in which they engage throughout the year (e.g., the ecological soap project they did before my arrival). For Becca, students must be told in advance what is going to be assessed and how. In some lessons I attended, Becca detailed the rubric to the students. She considers this may guide them in the process of solving the problem/doing the activity, and to make them understand that *"the important thing is not just the exam; everything they do every day counts"* (I-Be).

4.4.1.2. Becca's PCK of Scientific Explanation. Introduction

In order to characterise Becca's knowledge, beliefs, and teaching enactments regarding the practice of explanation construction, in the next sections, I describe her understanding of scientific explanation, her views on the relevance of this epistemic practice for scientists, and her intended learning goals related to this practice. I then analyse the instructional practices used by Becca to encourage her students to develop explanations and her assessment practices for evaluating students' efforts to achieve this objective. Table 4.4.1.a summarises some relevant information from the following sections that may be pertinent to my research questions. In Table 4.4.2.b, I present one vignette to illustrate the type of episodes we can find in Becca's case regarding scientific explanation production.

<table>
<tr><th colspan="4">BECCA</th></tr>
<tr><th colspan="4">Orientation Toward Science (OTS)</th></tr>
<tr><th>Knowledge/beliefs about the goals of science</th><th>Knowledge/beliefs about science teaching and learning</th><th>Teaching practice</th><th>Knowledge/beliefs about Scientific explanation</th></tr>
<tr><td>· Science as driving force for understanding the world
· Highlights experimental activities</td><td>· Teaching: a two-way process centred in the student
· Learning: active and practiced-based
· Self-recognised objectives: Awaken students' curiosity; Promote students' reasoning; Help student connect pieces of knowledge</td><td>·Lessons plan: flexible
· Content: scant but purposively selected
· Practice: project-based, cooperative, and problem-based.
· Incorporation of new technologies
· Plenty of opportunities to engage in authentic disciplinary practices</td><td>· Assortment of meaning for the verb 'explain' (explanations, explications and justifications)
· Constructing explanations is a means, not an end</td></tr>
<tr><th colspan="4">Knowledge of Instructional Strategies (KIS)</th></tr>
<tr><th>Communicative approaches</th><th>Activities</th><th>Language devices</th><th>Interaction patterns</th></tr>
<tr><td>·Interactive/Dialogic (7)
· Interactive/ Authoritative (5)
· Non-interactive/ Authoritative (3)</td><td>· Cooperative activity
· Oral presentation
· Self-assessment
· Modelled experiment
· Thought experiment
· Whole-class experiment</td><td>· Questions
· Requests/invitations
· Repetitions
· References
· Summaries</td><td>· Student intervention sequences
· IRF sequences
· Interruptions</td></tr>
<tr><th colspan="4">Knowledge of Assessment (KAs)</th></tr>
<tr><td colspan="2">Dimensions to Assess</td><td colspan="2">Methods</td></tr>
<tr><td colspan="2">· Content acquisition
· Students' engagement in practices
· Lab work, presentations</td><td colspan="2">· Rubrics
· Peer-assessment and self-assessment
· No specific model/instrument to assess students' explanations
· Informal assessment</td></tr>
</table>

Table 4.4.1.2.a) Summary of Becca's PCK of scientific explanation.

Table 4.4.1.2.b) Vignette #1. Example of explanatory episode in Becca's observed lessons.

TEACHER	***BECCA***
VIGNETTE/EPISODE/OBSERVATION	***V#1 / E#3 / Y9.O2-Al***
TOPIC	***Changes of state***

Be.- *We are going to use a cooperative-work dynamic that we all know very well: the 1-2-4 (…). You will have a minute to think individually, a minute to share as a couple, and a minute to reach agreement as a whole team. I'm going to write an observation on the blackboard, and we'll get a question from it. Then, first in an individual way, then in pairs, and then as a team, you have to propose a hypothesis... What was a hypothesis?*
S1.- *A hypothesis is what you believe before having the result*.
Be.- *And*?
S2.- *It is an idea that you have of something.*
S3.- *It may be true or not.*
S4.- *You do not know what can happen.*
S3.- *You have to check it.*
Be.- *It is an idea that must be provable. We are not going to ask ourselves if an experiment can be done to prove it. There are ways, but we are not going to question about them. You simply imagine that there is some experiment that can be done to demonstrate the hypothesis that you think. Ok, the observation is: 'the temperature remains constant during a change of state'. Have we observed that in the laboratory?*
SS.- *Yes.*
Be.- *The question is 'why'. You have some minutes to think, go!* (…)
S1.- *Because when changing from one state to another, it remains at an average temperature between the two states.*
S2.- *We think that it is due to the atmospheric pressure.*
S3.- *When changing from one state to another, the particles are separating little by little during a certain time. And at that moment the temperature is constant. In the solid, the particles are joined. And in the liquid, they are separated. At the end of that process, the change in state has taken place, and the temperature continues rising.*
S4.- *We think that the temperature remains constant because it takes some time to reach a certain temperature..., mmm, it's like it warms up very slowly*.
S5.- *We think that the change must be identified, and to do so, the raising or lowering of the temperature must stop. We need to identify when the state has changed, to know when it has become liquid. There's a time when it has finished changing its status ...*
S6.- *Because it takes time to change the temperature. There are certain temperatures that are more difficult for the liquid.*
S7.- *The temperature remains constant because as it is neither one state nor the other and it is a process, it needs to have a temperature that does not vary, so that it can pass to the next state. And when the state changes, the temperature begins to rise.*
Be.-*Ok, now, we are going to try to look for information about this, to see if someone can help us clarify it. With the help of your iPads, look for a hypothesis; it's a teamwork.*
Be.- *We can pose the question in a different way: the energy that I am releasing to the matter in the form of heat…, what is happening to it? where does it go?*
S1.- *The heat energy is focused on changing the state of the water and not on raising the temperature. That is, the energy is focused on the change of state.*
S2.- *The energy focuses on separating the molecules*.
Be.- *Let's see. How are the particles in a solid? They are together and organised. And when I give them some calorific energy... how are the particles of the solid: quiet or moving?*
SS.- *Moving*.
Be.- *And what was the name of that movement of solid particles?*
SS.- *Vibration*.
Be.- *So, by providing them with some calorific energy, will the particles start to move faster or slower?*
SS.- *Faster*.
Be.- *Do you remember when we went out to the playground and we did the activity of 'I am a solid', that we did not move? Well, for that energy, my group's companions have bothered me so much that in the end what I want is to move, and I become a liquid. Liquids flow. If we continue to increase the temperature, the particles will move even faster, until there comes a time when that energy is spent in transforming the liquid into gas.* And how was the movement of the gas particles? In 3-D, very well, and occupying all the possible space. *That is, the temperature remains constant because the energy we give to it is not spent in raising the temperature, but in changing the order of the particles, so they move from one state to another state*.

4.4.1.3. Orientation Towards Science (OTS): Becca's knowledge and beliefs about Scientific Explanation

When, in our interview, I asked Becca to define science, she got surprised –"*Oh Gosh! So difficult!*". The answer she gave me was rather broad, but in line with her goals and beliefs about science teaching. According to her:

"(S)cience is like (…) the engine that moves everything in the world; (it's) what awakens curiosity in the human beings and push them to want to know more. So, it seems to me that human beings, with their curiosity, ask questions and demonstrate them through science, and that is what causes new questions to arise, and the process to start again…" (I-Be)

Becca, with no prompt from me, added that she finds *"scientists' attempts to try to explain why things happen*" fascinating. When asked to delve into her answer by telling how scientists can achieve this latter goal, Becca said she was not very clear on it, but referred to "*the thorough and routine"* lab work. Becca considers that the complexity involved in actual lab work cannot be simplified down to the students' level –"*especially, if there is no a proper lab*"– so that it is not possible to replicate in the classroom what she believes to be the day-to-day of a scientist. However, she thinks they can emulate scientists in their search for explanations for observed phenomena: "*for example, the experiment [the students] did last week about the gas laws. I gave them a series of guidelines, and they had to find an explanation about why that had happened; why that and no other thing."* (I-Be).

Across the 32 classes I observed, I found 19 episodes in which Becca asked her students *to explain something*. The length of these episodes, and their relevance for the general objectives of the lesson, varied enormously, from a brief question during students' oral presentations (E#1-Be), to full activities that took a large part of a lesson and even more than one class –"*In their videos, they include explanations of the experiments, based on the laws they know*. (…). *These experiments have been searched by them on the Internet, and they have practised them at home."* (Y10.O1-Be).

All the explanatory episodes, except two, were initiated by Becca. In the two cases in which a student posed a seeking-why question, Becca opted for closing the episode quickly, either changing the topic or just continuing with her speech. Thus, she decided not to pursue the students' questions even though they denoted, in my opinion, curiosity and a deep comprehension of the issues being addressed. For instance, in the last session within the unit on changes of state, Becca played a video in which the sublimation of iodine was shown. They had spoken of this change of state in a previous lesson, but no group had done any experiment about it. When the video finished, one of the students asked Becca: *"Miss, you could squeeze a bowl [full of liquid] ... if the particles started to come closer and closer, in the end, it would become a solid, right?"* (E#4, Y9.O5-Be). Becca replied quite effusively that that was not the case and asked the pupil why he thought that; but before giving him time to answer, she changed the topic and began talking about the exam, so the episode was closed down. I believe that the student's question reflected a broad understanding of the underlying mechanisms of the phenomenon of change of state, and a high ability to reason and apply the acquired knowledge to new situations. Becca could have leveraged the question to introduce concepts such as liquefaction and give examples of everyday life (e.g., butane gas cylinder). But perhaps due to lack of knowledge, lack of time, or simply because she considered that the student was not going to understand her answer, she preferred not to respond to this request.

In the observed episodes, Becca asked students to produce explanations with the purpose of 1) Introducing concepts (e.g., gravity: E#16-Be); 2) Helping students understand 2.i) Concepts and properties (e.g., solubility: E#12-Be), 2.ii) General laws (e.g., laws of gases: E#7-Be), and 2.iii) Mechanisms that underlie phenomena (e.g., changes of state: E#3-Be); 3) Making students reflect about practical procedures instead of just following the given instructions (E#2-Be); and 4) Confronting students' misconceptions/misunderstandings (e.g., free fall: E#15-Be). Similarly, she uses the process of crafting explanations as a means to improve students' communication skills –"*reduce, simplify*" (E#17-Be), their ability to look up, select, and articulate quality information, and as an opportunity for group work, since students must learn how to negotiate their ideas with others: "(N)*ow we are going to try to look for information about this, to see if someone can help us clarify this. With the help of your iPads®, look for a hypothesis; it's a teamwork"* (E#3-Be). Finally, she also included explanation construction for students to learn how science works, being this part of a broader pedagogical strategy employed to promote learning in inquiry-based environments.

Despite the assortment of purposes deployed to include student-made explanations in the classroom, I found no evidence in Becca's enactment of explicitly addressing this practice, a crucial element in supporting students' explanatory skills (McNeill & Krajcik, 2008). Only in Episode 11, Becca gives a direct and specific instruction to a student about how she should construct the explanation –"*I want you to explain it to me according to what happens to the particles"* (E#11-Be)–. In the other episodes, Becca uses some strategies to guide the students in the process, but she does not teach this epistemic practice explicitly. This may suggest that, for her, the production of explanations is not an end, but a means to introduce and deepen content knowledge, and to strengthen some students' thinking and practical abilities.

From the 19 episodes categorised as 'explanation construction', only the meaning of nine of them could fit within what I have operationalised as 'scientific explanation' –namely, those aligned with scientific principles and grounded in empirical data (Kang *et al*., 2017)–. Within this category, there are examples of causal/mechanistic explanations (§2.5.2) and anthropomorphic explanations (in which human characteristics/intentions are endowed to inanimate entities). Furthermore, some of the explanations requested by Becca from the students may be classified as non-scientific explanations. Within this category, we find justificatory, clarificatory, and metacognitive explanations. In justificatory explanations, students were requested to provide some reasons to justify their answer to a certain question; in clarificatory explanations, students must elucidate the meaning of scientific terms; finally, in metacognitive explanations, students were asked to make explicit the steps they had followed to arriving at a solution/result. Table 4.4.1.3 shows some examples of each of these types of explanations, which correspond to a meaning of 'explanation' very different from what curricula, reform and policy document deem as one of the fundamental aspects of scientific literacy (§2.2).

Although in her instruction Becca makes use of different senses for the voice 'explain', when asked explicitly in the interview, she talked in terms of everyday use of this term; namely, as providing a set of statements that give details or reasons in order to help another person understand something:

> *"Sometimes (the students) ask some questions for which I, since they do not have all the knowledge that is needed to understand it, give a very simplified explanation; I just let it out and they get what they can. But we try that the classes are not like this, but to pose a question so that they think, investigate… Sometimes it is not for them to investigate, but to see what they would say, like 'if I ask you this question, what would you say? You have your previous ideas, just let them out, put them together, and then we will compare them; we will look for information in another site, and we will arrive at an explanation that seems coherent to all of us, or that we all understand'. Then, I add something that I think can clarify some concepts that may be a bit confusing." (I-Be)*

In this dissertation, I am referring to this practice as 'explication', to make a clear distinction with my operational definition of scientific explanation (§2.5.4).

Table 4.4.1.3) Different meanings of 'explanation' found in Becca's observed lessons

TYPE OF EXPLANATION	*EXAMPLE*
SCIENTIFIC EXPLANATION	**Articulation of theoretical and background knowledge to make sense of a certain phenomenon through a process of reasoning**
Causal/ Mechanistic	S1.-*If we put the bottle in hot water, we will see that the walls of the balloon expand,* ***because the heat causes the particles of the gas to move faster and go further****: that is why the balloon expands. But if we put it in icy water, we will see how the balloon decreases, since the cold makes the particles of the gas do not move so fast or go so far*. (E#6; Y10.O2-Be) Be.- *We were saying that this is pure water (well, let's suppose it is distilled water, although it's tap water), and the egg is our density-meter. We put the egg, and it sinks (…). Now, we add some salt. What happened before? That the egg had sunk.* ***Why? How was the density of the egg compared to the density of the water before?*** SS.- *Higher*. Be.- *Higher, and that's why it was sinking*. (E#6; Y11.O1-Be)
Anthropomorphic	Be.- *Do you remember when we went out to the playground and we did the activity called 'I am a solid', that we did not move? Well, for that energy,* ***my group's companions have bothered me so much that in the end what I want is to move, and I become a liquid****. Liquids flow*. (E#3; Y9.O3-Be)
NON-SCIENTIFIC EXPLANATIONS	**Different meanings**
Clarifying concepts	Be.- *We said that water is made up of oxygen and hydrogen…so****, why is it not a mixture that is made up of two things?*** S1.- *Because it is formed by two elements.* Be.- *And what else? What other condition must it have so that we can say that it is not a mixture but a compound?* (E#5; Y9.O6-Be) Be.- *Well, can someone* ***explain to me what the position is****, from what you have read? Have you read 'trajectory'? And what is 'displacement'? Those two* ***concepts*** *are related, and* ***we are going to explain them now***. (E#18; Y11.O4-Be)

Table 4.4.1.3) Different meanings of 'explanation' found in Becca's observed lessons

TYPE OF EXPLANATION	*EXAMPLE*
Justifying a procedure	Be.- *In the protocol, it was said that the thermometer could not touch the bottom of the glass or the walls;* ***why do you think it was said that?*** *If you put the thermometer touching the bottom of the glass, which is in direct contact with the plate, what will you be measuring: the temperature of the water or the temperature of the plate*? S1.- *Of the plate*. Be.- *Of the plate, but that is not what we wanted to measure*. (E#1; Y9.O1-Be)
Justifying an answer	Be.- *Imagine a place of those that are barely left on the planet, where there is absolutely no pollution. In that situation, will the air be a pure substance, Alice? Take a chance and* ***give an answer***. S1.- *No.* A.- ***Why?*** S1.- *Because air is made of more than one compound, it contains many gases.* (E#5; Y9.O6-Be)
Justifying a mathematical representation	*A.- Angel has written something there on the board, and I want you to think whether those will be the units of acceleration or not. (…)* *S1.- It's metres per seconds squared.* *A.- But have you looked for it somewhere?* *S1.- It's here [pointing at the textbook]* *Be.- But what I want is* ***for someone to explain why acceleration has those units****. (...) Let's see it quickly. The units of acceleration must come out of the equation we have set for acceleration, right? Up we have the speed... What is the unit of speed? m/s. Down we have put time. What is the unit of time? Seconds. How is that done mathematically? As a division. Hence, the unit of acceleration is* m/s^2. (E#19; Y11.O6-Be)
Metacognitive	Be.- *Alfred has obtained 20.6 m/s, but he has not used any equation. He has used a reasoning procedure, okay? Let's see if you get the same. (...)* ***Can you explain how you came to the reasoning that you were saying?*** S1.- *Because every second*... Be.- *But to calculate, what? Because we do not know what you're calculating ... to calculate the speed at three seconds, right?* S1.- *As it started at 50m/s and every second it is 9.8m/s slower, I subtracted 9.8 three times*. (E#17; Y11.O12-Be)

4.4.1.4. Becca's Knowledge of Instructional Strategies (KIS)

As the description in the previous sections shows, Becca is an experienced and creative teacher, who deploys a huge variety of teaching strategies in accordance with her beliefs and learning objectives. Although the development of explanatory skills does not seem to be one of these objectives, during my stay with Becca, I could observe some episodes in which her students engaged in a process of explanation building for a given phenomenon. In this section, I report and analyse the actions and communicative strategies Becca implements to guide students in this practice.

I used Mortimer and Scott's analytical framework (Figure 3.7.2.b) to portray Becca's communicative approaches. Among the 19 observed episodes, I found a relatively even distribution between the Interactive/Authoritative communicative approach (five episodes) and the Interactive/Dialogic communicative approach (seven). The Non-interactive/Authoritative communicative approach appears only three times. There was no evidence of Non-interactive/Dialogic communicative approach episodes, and four episodes were not classifiable under these labels because they were not, properly speaking, part of classroom dialogue (Table 4.4.1.4.a).

When Becca interacts with her students, she uses different strategies, depending on whether she wants to lead them to a specific idea (Interactive/Authoritative approach) or she prefers the students to inquire about different options and perspectives (Interactive/Dialogic). In some Authoritative episodes (e.g., E#5-Be), Becca selects the answers that interest her and raises a series of questions, each one more concrete than the previous one, to drive the students towards the answer she has in mind. She also uses a particular tone of voice to highlight certain parts of a statement, to mark key meanings. The information in which she is not interested is ignored or directly discarded. On the other hand, in Dialogic interventions (e.g., E#3-Be), Becca does not reject or reinforce any position, but she makes the students see that there are several options, and that they should try to reason which one of them seems the most suitable or accurate. Finally, in the three episodes with a Non-interactive/Authoritative approach, Becca presents one specific point of view. And though she frames a series of questions, it is she who answers them, without allowing the students to intervene (e.g., E#11-Be). These episodes are usually very brief, and they are inserted within broader and more interactive communicative exchanges; in fact, Becca only uses this last approach when she wants to save some time –"*(w)ith what magnitude of which we have studied is this related? Well, I give you the answer because we do not have much time*" (Y11.O1-Be).

Table 4.4.1.4.a) Becca's communicative approach for the episodes on explanation

COMMUNICATIVE APPROACH	EPISODES	EVIDENCE
Interactive/ Authoritative	1; 4; 5; 13; 17	*Be.- Why could it be?* *S3.- Because one has more graphite.* *Be.- No, I do not care about the pencil that I use.* *S4.- Because water has more component ..., more ...* *Be.- **More what of what? What was the water like?*** *SS.- H2O.* *Be.- **Ok, then, each molecule of water... what is it made of?*** *S4.- Two elements.* *Be.- **Okay, but it will have two [atoms of] hydrogen and one [atom of] oxygen. I mean, it has double ...*** *S5.- Why?* *Be.- **Because the water molecule is like that. Come on, we're getting off the topic** (...)* (E#5; Y9.O6-Be)
Interactive/Dialogic	2; 3; 11; 15; 16; 18; 19	*Be.- Let's see. If I threw this [book plus paper], was it there one that fell faster, or did both fall the same way?* *S1.- The book falls faster because it is heavier.* *Be.- Because it is heavier... but if we made a ball, and we threw it, they fell the same ... and this [the paper] weighs less than this [the book] ...* *S2.- **But more air passes...*** ***Be.- Trough where?*** ***S3.- Because it is not a flat surface, there's no air that slows it down...*** ***S4.- Molecules are closer together in the crumpled paper.*** *Be.- So, if I drop the book or the paper... We have to calculate how fast this paper falls. I give you another opportunity. I am asking you to calculate the speed, not the time it takes to fall... **How do you calculate the speed?*** ***S5.- There is a formula.*** ***S4.- It is accelerated.*** *Be.- If I drop the paper, will it fall with a constant speed or will it go faster and faster? Or will it go increasingly slow?* *S6.- Increasingly faster.* *S4.- Constant.* *Be.- **We have three possibilities: that it always goes at the same speed, that each time it goes faster or that it decreases its speed. What do you think it's going to do? But do not look for it in the book, try to think about it by yourselves**.* (E#16; Y11.O9-Be)
Non-interactive/ Authoritative	10; 12; 14;	Be.- *Solubility depends on the temperature. **It's true. Why? Because we had said that, at higher temperatures, the particles of the solvent moved faster and there was more space for the particles of the solute to fit**.* (E#14; Y11.O3-Be)
Non-interactive/Dialogic	-----	-----
Non-classifiable*	6; 7; 8; 9	-----

Becca took a series of actions in the classroom to bring each specific communicative approach to life. This included i) proposing variated activities; ii) intervening through a diversity of discourse moves; and iii) engaging in different patterns of interaction. In what follows, I analyse all these actions, specifying the strategies used and providing some examples of the selected episodes as an illustration. Concerning the role that the construction of an explanation plays in relation to an activity, we find two possibilities: a) The formulation of the explanation *is* the activity itself. In other words, Becca proposes activities that consist of elaborating an explanation for a phenomenon. Within this category, we can locate Episode 3, in which Becca suggests the use of a cooperative activity to arrive at an agreed explanation about why the temperature remains constant in a change of state (E#3-Be, Table 4.4.1.b). Similarly, there are four episodes (E#6-Be to E#9-Be) in which students must prepare a presentation to communicate their explanation of an observed phenomenon (based on gas laws); or b) The elaboration of the explanation is a means, an accessorial part of an activity targeted at promoting understanding and/or eliminating a misconception. This activity may be one instructional explication performed by Becca, or an experiment (thought, modelled, or whole-class based).

In Table 4.4.1.4.b, there are examples for all the types of activities present in Becca's explanatory episodes. Regardless of the purpose of the activity, all of them have in common that they are oral practices in which there is a strong interactive component, either teacher-student or student-student. Producing an explanation in Becca's context can be conceived, then, as an exercise of knowledge co-construction which is collective, reciprocal, supportive, cumulative and purposeful. Given that these are the five core principles that Alexander (2008) attributes to the dialogic teaching, we can say that, for Becca, constructing an explanation is a form of classroom dialogue. Therefore, the most relevant instructional strategies to be analysed are those in which language is present.

The first thing that should be highlighted in Becca's instructional practices regarding the construction of explanations, is the great and varied number of discourse moves that she makes. In Chapter 3 (§3.7), I made a detailed description of how I conducted the analysis of the communicative acts that my participants used to drive their students in the explanation-building process. These communicative moves were grouped into seven clusters, namely: Initiating, Continuing, Extending, Referring-back, Replying, Commenting/Reinforcing and Concluding moves. Table 4.4.1.4.c particularises such moves for Becca, providing, in addition, some examples as evidence for each strategy used.

Table-4.4.1.4.b) Types of activities present in Becca's episodes on explanation.

TYPE OF ACTIVITY	EXAMPLES
Cooperative activity	*Be.- **We are going to use a cooperative-work dynamic that we all know very well: the 1-2-4 (for us, the 1-2-table). You will have a minute to think individually, a minute to share as a couple, and a minute to reach agreement as a whole team**. I'm going to write an observation on the blackboard, and we'll get a question from it.* (E#3; Y9.O2-Be)
Oral presentation	**[E-FN: In their videos they include explanations to the experiments, based on the laws they know**] *S1.-If we put the bottle in hot water, we will see that the walls of the balloon expand, because the heat causes the particles of the gas to move faster and go further: that is why the balloon expands. But if we put it in icy water, we will see how the balloon decreases, since the cold makes the particles of the gas do not move so fast or go so far.* (E#6; Y10.O2-Be)
Activity checking/assessment	*Be.- Now, I have a container filled with a gas, with a moving piston, like the syringe that many of you have used in your experiments. Now, if I raise the temperature - **I do not care which law is, now we think about it. I am just making a reasoning** -, what will happen to the particles of that gas: will they move faster, or will they move slower? Faster, right? If they move faster, they will push the piston so that the volume will…, they will try to occupy greater volume. If I increase the temperature, the volume will increase, as long as I keep the pressure constant.* (E#10; Y10.O3-Be)
Modelled experiment	***Be.- What did we want to do this experiment for? Do you remember?*** *S1.- To see something related to the density…* *Be.- For something about density, ok. So, we were saying that this is pure water (well, let's suppose it's distilled water, although it's tap water), and the egg is our density meter. We put the egg, and it sinks (…). Now, we add some salt.* *Be.- **What happened before? That the egg had sunk. Why? How was the density of the egg compared to the density of the water before?*** *SS.- Higher.* *Be.- Higher, and that's why it was sinking.* (E#13; Y11.O1-Be)
Thought experiment	*Be.- Look. **Imagine that I jump from this table. Imagine that, instead of jumping from the table, I jump from the balcony of my mother's house, who lives on a fourth floor. Do you think that the effect on my body will be the same if I jump from the table or from my mother's house?** My mass is the same in both cases...* *S7.- Due to the acceleration of gravity.* (E#16; Y11.O9-Be)
Whole-class experiment	Be.- ***Ok, now we have to take a book (or a notebook) and a paper sheet. We have to do the following; let's drop the book (…). And now let's drop the paper sheet. (…) Let's drop them both at the same time from the same height. Stand up. 1, 2, 3!** Don't sit down! Now, let's put the sheet on top of the book and we'll drop them: 1,2 and 3! Have you noticed any difference between before and now? Let's do it again. (…) **Now, question: why does the book and the paper fall at different speeds when they are separated, but fall at the same speed when they are together?*** *S1.- Because they behave like a single body.* *Be.- Why? Ok, I change the question. Why does it take longer for the paper to fall than the book when they are separated?* *S2.- Because the book weighs more.* *Be.- Sure? Now let's make a ball with the paper. We drop them at the same time: 1, 2 and 3! Now, what?* (E#15; Y11.O3-Be)

Table 4.4.1.4.c) Discourse moves present in Becca's episodes on explanation

BECCA'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Initiating moves	Direct instruction (new problem)	*Be.- **We are going to use a cooperative-work dynamic that we all know very well: the 1-2-4 (for us, the 1-2-table). You will have a minute to think individually, a minute to share as a couple, and a minute to reach agreement as a whole team**. I'm going to write an observation on the blackboard, and we'll get a question from it.* (E#3; Y9.O2-Be)
	Reasoning question	*Be.- We said that water is made up of oxygen and hydrogen...so, **why is it not a mixture that is made up of two things**?* *S1.- Because it is formed by two elements.* (E#5; Y9.O6-Be) Be.- **Now, question: why does the book and the paper fall at different speeds when they are separated, but fall at the same speed when they are together?** S1.- Because they behave like a single body. (E#15; Y11.O3-Be)
	Recalling/ Factual question	*Be.- **Do you remember that we saw the [concept of] solubility? What was solubility?*** (E#12; Y11.O1-Be) Be.- **What did we wanted to do this experiment for? Do you remember?** S1.- To see something related to the density… Be.- For something about density, ok. (E#13; Y11.O1-Be)
Continuing moves	Direct instruction	*Be.- Ok, **now we are going to try to look for information about this, to see if someone can help us clarify this**. With the help of your iPads, look for a hypothesis; it's a teamwork.* (E#3; Y9.O2-Be)
	Factual question (giving options)	*S2.- They separate and move faster.* *Be.- They will move even faster, and they will separate more. So, what will happen? **Will they hit the walls of the container more times, or less?*** *SS.- More.* (E#11; Y10.O3-Be) Well, we have added salt, we have managed to change the density of the water, and now… **is the water denser than the egg, or the egg is denser than the water?** SS.- The water is denser. (E#13; Y11.O1-Be)

Table 4.4.1.4.c) Discourse moves present in Becca's episodes on explanation

BECCA'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Continuing moves	Reasoning question (rephrasing)	*S1.- Because they behave like a single body.* *Be.- **Why? Ok, I change the question.** Why does it take longer for the paper to fall than the book when they are separated?* *S2.- Because the book weighs more.* (E#15; Y11.O3-Be)
	Guiding question	*S4.- Because water has more component ..., more ...* *Be.- **More what of what? What was the water like?*** *SS.- H2O. (*E#5; Y9.O6-Be)
	Asks for a clarification	*S7.- Due to the acceleration of gravity.* *Be.- **And what is that?*** *S7.- The 'g'.* (E#16; Y11.O9-Be) Be.- [H]ow are the particles of the solid: quiet or moving? SS.- Moving. Be.- **And what was the name of that movement of solid particles?** SS.- Vibration. (E#3; Y9.O2-Be)
	Asks for justification	Be.- **You say that speed is constant, why?** S4.- Because there's nothing to push it down. (E#16; Y11.O9-Be)
	Invites reasoning	*S5.- Because if you crush it, it's all together and there are no air gaps.* *Be.- **And what consequences can this have?*** *S4.- That the thermometer would take the temperature of the air.* (E#2; Y9.O2-Be) *S2.- But more air passes…* *Be.- **Trough where?*** *S3.- Because it is not a flat surface, there's no air that slows it down…* (E#16; Y11.O9-Be)

Table 4.4.1.4.c) Discourse moves present in Becca's episodes on explanation

BECCA'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Continuing moves	Invites elaboration	Be.- *What was a hypothesis?* *S1.- A hypothesis is what you believe before having the result.* *Be.-* ***And?*** *S2.- It is an idea that you have of something.* *S3.- It may be true or not.* *S4.- You do not know what can happen.* *S3.- You have to check it.* (E#3; Y9.O2-Be) *Be.- We said that water is made up of oxygen and hydrogen…so, why is it not a mixture that is made up of two things?* *S1.- Because it is formed by two elements.* *Be.-* ***And what else? What other condition must it have so that we can say that it is not a mixture but a compound?*** (E#5; Y9.O6-Be)
Extending moves	Challenges degree of certainty	Be.- Why does it take longer for the paper to fall than the book when they are separated? S2.- Because the book weighs more. Be.- **Sure? Now let's make a ball with the paper. We drop them at the same time: 1, 2 and 3! Now, what**? S3.- They fall at the same time. (E#15; Y11.O3-Be)
	Ignores an answer and changes direction	*Be.- And what is that?* *S7.-* ***The 'g'.*** ***Be.- Let's see. Why is it more dangerous to jump from the balcony of a fourth floor than jumping from the table?*** (E#16; Y11.O9-Be)
	Rhetorical questioning	*Be.- Do you remember that we saw the [concept of] solubility?* ***What was solubility? The maximum amount of solute that I can dissolve in a certain solvent at a certain temperature****. It will be related to the [concept of] saturated solution.* ***What did it depend on? It depended on the amount of solvent that I have, on what solvent I have and on what solute I want to dissolve, and on what else? On the temperature****.* (E#12; Y11.O1-Be)

Table 4.4.1.4.c) Discourse moves present in Becca's episodes on explanation

BECCA'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Referring moves: Makes explicit links to	Prior activities /situations	*Ok, the observation is: "the temperature remains constant during a change of state".* ***Have we observed that in the laboratory?*** *Ss.- Yes.* *Be.- The question is 'why'.* (E#3; Y9.O2-Be) *Be.-* ***Do you remember when we went out to the playground and we did the activity of 'I am a solid', that we did not move****? Well, for that energy, my group's companions have bothered me so much that in the end what I want is to move, and I become a liquid.* (E#3; Y9.O2-Be)
	Prior contributions	*Be.-* ***But you said that the paper took longer to reach the floor because it was less heavy than the book****… when making a ball with the paper, has its weight changed?* *Ss.- No.* (E#15; Y11.O3-Be)
Replying moves	Responds to explicit comments	*Be.- The water is denser, so…* *S1.-* ***But the egg weighs more!*** ***Be.- But here we are not talking about weight, but about density****.* (E#13; Y11.O1-Be)
	Refuses to answer a question/go deeper	*Be.- Okay, but it will have two [atoms of] hydrogen and one [atom of] oxygen. I mean, it has double …* *S5.-* ***Why?*** ***Be.- Because the water molecule is like that****.* ***Come on, we're getting off the topic****.* (E#5; Y9.O6-Be)
Commenting /reinforcing moves	Makes a motivational statement	*Be.- That is, if the temperature increases, the pressure increases.* ***Good!*** (E#11; Y10.O3-Be)
	Repeats (adding some information)	*Be.- And the gas particles, how did they move?* *SS.-* ***In 3-D.*** ***Be.- In 3-D, very well, and occupying all the possible space****. (E#2; Y11.O2-Be)*

Table 4.4.1.4.c) Discourse moves present in Becca's episodes on explanation

BECCA'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Concluding moves	Summarises (by naming a concept/idea)	Be.- ***The objects do not fall with constant speed, they fall accelerating. Yesterday we said that today we were going to study the free fall movement, which is a type of UARM***. (E#16; Y11.O9-Be)
	Provides correct answer	Be.- [I]*f I raise the temperature (…), what will happen to the particles of that gas: will they move faster, or will they move slower? Faster, right? If they move faster, they will push the piston so that the volume will…, they will try to occupy greater volume.* ***If I increase the temperature, the volume will increase, as long as I keep the pressure constant.*** (E#10; Y10.O3-Be)
	Summarises (by repeating)	*Be.- In 3-D, very well, and occupying all the possible space.* ***That is, the temperature remains constant because the energy we give to it is not spent in raising the temperature, but in changing the order of the particles, so they move from one state to another state***. (E#3; Y9.O2-Be)
	Summarises (by rephrasing)	*Be.- And what consequences can this have?* *S4.- That the thermometer would take the temperature of the air.* *Be.-* ***We crush to have a homogeneous substance, so that what we measure is more real***. (E#2; Y9.O2-Be)
	Summarises (and adds some information)	*Be.- [I]f we have the supersaturated [solution] and it is cooled down, what will happen?* *S2.- It separates.* *Be.-* ***All that did not fit at that temperature precipitates again to the bottom. That is why the solubility had to be defined with respect to a certain temperature***. (E#12; Y11.O1-Be)
	Refers to the future	*Be.- But here we are not talking about weight, but about density.* ***We'll do this again when we are in the topic of hydrostatics.*** (E#13; Y11.O1-Be)
	Refers to a real situation	*Be.- [W]e will check, tomorrow (…) that in one of the pencils more bubbles are formed than in the other, twice as many bubbles are formed in the other, because water has twice the hydrogen that of oxygen, okay? We will not be able to measure exactly how much oxygen comes out or how much hydrogen, but* ***in a laboratory with the right materials you can collect the amount of hydrogen that comes out and the amount of oxygen. And you could verify that it should be double.*** (E#5; Y9.O6-Be)
	Changes of topic	*Be.- But here we are not talking about weight, but about density. We'll do this again when we are in the topic of hydrostatics.* *S2.-* ***Is the sea water saturated?*** ***Be.- Well..., I do not think so, but it's a good question, why do not you research about it?*** (E#13; Y11.O1-Be)
	Does not give a final answer	Be.- *When making a ball with the paper, has its weight changed?* Ss.- *No.* Be.- *But now they have fallen at the same time…* ***curious… ok, sit down.*** (E#15; Y11.O3-Be)
	Reaches certain agreement	Be.- *Ok.* ***I already think that more or less everyone is in this****. The objects do not fall with constant speed; they fall accelerating.* (E#16; Y11.O9-Be)

My analysis of Becca's discourse moves shows that the elaboration of an explanation usually starts with an explicit initiating move, being this a direct instruction (when Becca proposes the students to build an explanation for a certain phenomenon) or a question. In several episodes, we find examples of Recall/Factual questions –which require learners to recall existing information (E#13-Be)– and of Reasoning questions –which demand students to use their background knowledge to generate and/or connect different pieces of information (E#5-Be). Sometimes, before requesting the students to explain something, Becca makes a short exposition to contextualise the phenomenon:

> *Be.- Now, instead of keeping the pressure fixed, we will keep the volume fixed, we will keep it constant. How? Well, instead of putting a container with a piston, we have a closed and rigid bottle. I have a gas there, and I increase its…, I heat it up, I increase the temperature.* ***What will happen to the pressure: will it increase or decrease?***
>
> *Ss.- Increase.*
>
> *Be***.- Why?** *(Y10.O3-Be)*

The Initiating move generally leads to a series of conversational turns which are shaped by Continuing or Extending moves. Becca uses different types of questioning to guide students in the building process, encouraging them to elaborate and expand either their own or their peers' reasoning. In these cases, they construct the explanation jointly. Sometimes, though, Becca performs all the explaining, but she involves the students in the process through probing questions. Becca gets the students to circumscribe the explanation by slipping in the conversation some interventions designed to stimulate, and/or to make the students connect what they are doing with something they have already learned. This supposes, also, that Becca sometimes decides to ignore the information provided by a student or that she decides to change the direction of the dialogue if she believes they are moving away from the intended goal. Finally, Becca closes the episodes on explanation in different ways, three of which stand out: providing the correct explanation explicitly and completely, summarising everything that has been said –highlighting what she considers most relevant– and leaving the question unanswered. Becca also refers to something that will be discussed in a future session or something that the students already know.

My data from Becca's lessons show that the process of crafting an explanation required an alternation of verbal interventions, especially in the most complex cases, which ended up constituting complete sequences. There are two types of sequences that are constantly repeated in the analysed episodes: Students' interventions sequences –in which several students reply without Becca making any comment– and the triadic IRF sequence (Mehan, 1979; Sinclair & Coulthard, 1992) – in which Becca Initiates an interplay, one student responds, and Becca evaluates the answer and encourages the student to Follow up with the reasoning in a specified direction. Finally, there was an episode in which the sequence of reasoning is abruptly closed because a student interrupts the teacher. In Table 4.4.1.4.d, I show examples to illustrate these patterns of interaction.

Table 4.4.1.4.d) Becca's patterns of interaction.

BECCA'S PATTERNS OF INTERACTION	EXAMPLES
Student interventions sequences	*Be.- Why was it necessary to chop the ice?* ***S1.****- Because if we put big pieces, the experiment takes more time.* ***S2.****- Because if we use pieces too large, they do not fill gaps that are missing, and then, the thermometer does not get in touch with everything.* ***S3.****- Because it takes longer to become liquid.* ***S4.****- Because it would not mix well with salt.* ***S5.****- Because if you crush it, it's all together and there are no air gaps.* (E#2; Y9.O2-Be)
IRF sequences	*Be.-* ***What happens to them?*** *S2.- They separate and move faster.* *Be.- They will move even faster, and they will separate more.* ***So, what will happen? Will they hit the walls of the container more times, or less?*** *SS.- More.* *Be.- That is, if the temperature increases, the pressure increases.* ***Good!*** (E#11; Y10.O3-Be)
Interruptions	*Be.- Okay, but it will have two [atoms of] hydrogen and one [atom of] oxygen. I mean,* ***it has double ...*** ***S5.- Why?*** *Be.- Because the water molecule is like that.* (E#4; Y9.O6-Be)

4.4.1.5. Becca's Knowledge of Assessment (KAs)

In section 4.4.1.1, I reported that Becca had a well-developed Knowledge of Assessment that she drew on to assess students' knowledge and engagement in science disciplinary practices, such as designing scientific enquiry. However, after analysing the data collected, it became clear that she had not developed any practice-specific strategy for assessing students' ideas and performances on scientific explanation production.

Since Becca claimed to assess *everything*, this finding bewildered me at first. However, as research on the knowledge of assessment of experienced teachers has shown (Gearhart & Osmundson, 2009; Pareja, 2014), this knowledge is closely aligned with the curricular goals and the instructional strategies implemented. Since for Becca acquiring proficiency in producing explanations is not a final goal, and given that she does not have any purposely designed strategy for this epistemic practice, it is not surprising I could not find any example of formal assessment of this practice.

To the above, I must add that different forms of informal assessment did take place during Becca's lessons, which involved teacher-student interactions and observations of student-student interactions. Informal assessment occurred during instruction and was embedded within different activities. For instance, Becca relied upon questioning for formative assessment when students were working in collaborative groups and during whole-class episodes of explanation production, as was shown in the previous section. Nevertheless, it should be clear that, in these cases, the assessment strategies Becca implements are designed to direct the students towards a canonical explanation. That is to say, the questions she raises and the supporting comments she makes, do not have as a target to promote students' abilities to construct explanations.

We have an illustration of this in Episode #3 (Table 4.4.1.2.b), which is the most complete and relevant explanatory episode in Becca's case. This is an excellent example of co-construction, in which the students make their proposals as a group, to reach an agreed-upon explanation. It would have been a good opportunity to highlight and correct some mistakes that students present in their reasoning. Thus, we can see groups that provide irrelevant and/or incomplete information – "(*w)e think that it is due to the atmospheric pressure"*-; groups that commit reasoning contradictions – "(*w)e think that the temperature remains constant because it takes some time to reach a certain temperature*"-; and groups that incur circular reasoning – "(*t)he temperature remains constant because as it is neither one state nor the other and it is a process, it needs to have a temperature that does not vary, so that it can pass to the next state*". Becca does not comment on these attempts to explain the phenomenon, missing the opportunity to correct some of these errors and, with it, the opportunity to improve her students' ability to build high-quality scientific explanations.

4.4.1.6. Becca's PCK of Scientific Explanation. Summary and discussion

Becca shows a high consistency between those factors that might influence the implementation of explanatory practices in her classes; there is consistency between her beliefs about the teaching-learning process and her actions. Between her objectives and her instructional strategies. Between her instructional strategies and her assessment methods.

There is consistency between Becca's orientation towards science and how science is taught. Between her teaching practice and that of other School-B teachers.

As I have shown, Becca's science lessons are characterised by the creation of opportunities to engage in an assortment of epistemic practices. De Vries, Lund, and Baker (2009) use the term 'epistemic dialogue' to designate a specific type of activity that can be introduced in the science classroom. De Vries and her team characterise epistemic dialogues with three features: i) They take place in collaborative problem-solving situations; ii) They include both explanations and argumentations; and iii) They are conceived to target the conceptual knowledge underlying the problem-solving procedure, rather than the execution of problem-solving actions themselves (De Vries *et al.,* 2009, p. 64). Since many of the episodes observed in Becca's classes satisfy these three requirements (see, for example, the episode narrated in Table 4.4.1.2.b), we can affirm that Becca's teaching practice favours epistemic dialogue in the classroom. This type of activity enables students, on the one hand, to interact directly with natural phenomena and, on the other, to interact productively with their peers. The latter can happen because in Becca's classes, students participate in what Mercer (2010) calls 'exploratory talk'. So, thanks to the active and respectful listening of ideas and questions, the students work and build together towards a shared purpose (Monteira & Jiménez-Aleixandre, 2019).

Slavich and Zimbardo (2012) analyse different learning strategies to extract some common properties. These properties serve as the basis for characterising a broader approach to classroom instruction that they call 'transformational teaching'. The strategies they analyse are active learning, student-centred learning, collaborative learning, experiential learning, and problem-based learning. As the reader may have noticed, all these strategies appeared throughout my description of Becca's profile. The principles of transformational teaching urge teachers to encourage positive learning-related attitudes and beliefs and to formulate opportunities for learning-by-doing in a demanding but stimulating environment. Although Slavich and Zimbardo do not particularise their analysis for science classes, I venture to affirm that the conditions they describe seem to be the best ones to promote the teaching of science-as-practice, since it gathers in a single term what many authors of the field defend. If we consider that Becca satisfies, as far as my observations allow me to suggest, all these requirements, it is not surprising that in their classes, participation in epistemic practices has a central role.

In their proposal to develop a model for teaching argumentation in science classes, Ruiz-Ortega, Tamayo and Márquez (2015) declare that one of the requisites that learning environments must possess so that this practice may be incorporated is the problematisation of content knowledge. Ford (2008) maintains that problematising content requires students to be "asked to articulate interpretations of scientific ideas in light of data, entertain alternative possibilities, and try to achieve consensus" (p.420). Episode #3, together with other cases in which students try to craft an explanation, only make sense within the framework of content-problematisation under which Becca works. Engle and Conant (2002) suggest four guiding principles required for the production of learning environments in which students may productively engage in science disciplinary practices, and the problematisation of content is one of them. They say that "teachers should encourage students' questions, proposals, challenges, and other intellectual contributions, rather than expecting that they should simply assimilate facts, procedures, and other answers" (Engle & Conant, 2002, p.404). Berland *et al.* (2016) consider that, in the context of discipline-based epistemic practices, not only the content must be problematised, but also some aspects of the tasks and activities involved; otherwise, students could treat them as sequences of mechanical and meaningless steps. To avoid that the students, then, end up 'doing the lesson' instead of 'doing science' (Jiménez-Aleixandre *et al*., 2000), teachers should include explicit guidelines that invite students to consciously reflect on the practice in which they are involved. Their role under this approach is to serve as facilitators (Slavich & Zimbardo, 2012) who guide the learning process by modelling, scaffolding, challenging students intellectually, fostering responsibility and stimulating reflection.

Another condition proposed by Engle and Conant (2002) in their study on practice-based environments is the distribution of the epistemic authority. This distribution requires that the predominant voice is not that of the teacher, although she keeps a different role and continues to exercise logistical authority (Ford, 2008). We have seen that one of Becca's basic premises about learning science is that the student must be at the centre of the practice; and rather than acting as passive participants, they are actively involved both in the creation and in the validation of knowledge. By redistributing epistemic authority to everyone, Becca works towards the institution of a sort of science practice community within the classroom. Stroupe (2014) defines communities of practice as "context(s) in which teachers and students negotiate particular forms of disciplinary activity and knowledge" (p.489). If we listen to those voices that assert that epistemic authority in science is social (Ford, 2008), it can be inferred that authentic science learning requires communities of peers that make decisions concerning what counts as new knowledge through a process of dialectic and collaborative reasoning. That is, students must be provided with opportunities to co-construct, evaluate and critique their colleagues' explanations. Duschl (2008) adds that it is necessary to find the balance between the conceptual, epistemological and social aspects of any scientific practice in which students get involved. Since in Becca's case, the episodes of production of explanations are inserted in the bosom of collaborative activities, we can affirm that the social dimension of this practice is properly worked in the classroom. However, since Becca does not explicitly mention the elements that compose an explanation, nor does she allude to the criteria that determine what counts as a good explanation, it seems that it has not reached the harmony required by Duschl so that learning of his practice is effective.

As has been discussed, Becca utilises classroom discussions and students' presentations as opportunities for them to engage in the articulation of explanations verbally. However, even though these practices may provide opportunities for students to develop their understanding of and abilities with constructing explanations, there is no evidence that Becca did intentionally use concrete instructional strategies for these purposes. Based on the classification proposed by Yilmaz, Cakiroglu, Ertepinar, and Erduran (2017), I would say that the strategies used within Becca's activity-sequence are Basic. By this, Yilmaz and colleagues mean that these strategies may initiate or promote the construction of the explanation, but they do not delve into the structure and logical processes that underlie the process. That is, Becca's strategies do not include what Yilmaz calls Meta-level Instructional Strategies for explanation, nor the Meta-strategic Instructional Strategies for Explanation. Since these are the most relevant in teaching how to reason, its absence could make it difficult for students to adequately develop their explanatory reasoning ability.

4.5. Study's Context: An overview on the English educational system

In the UK Human Rights Act, it is stated that no person shall be denied the right to education[25]. The main agency responsible for safeguarding this right is the Department for Education. To create a new framework to "raise standards, extend choice and produce a better-educated Britain"[26], in 1988, the Education Reform Act was approved by this Department[27]. Although born amid a strong opposition, this Act made profound changes to the education system, and it is still regarded as the most important piece of education legislation in England since the 1944 Education Act (the so-called Butler Act) (Hansen & Vignoles, 2005). After the

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[25] Human Rights Act, Schedule 1, First Protocol, Article 2.
https://www.legislation.gov.uk/ukpga/1998/42/schedule/1

[26] House of Commons, 1 December 1987, col 771-772.
https://publications.parliament.uk/pa/cm199697/cmhansrd/vo961111/debtext/61111-28.htm

[27] Since its promulgation, the Education Reform Act has been slightly altered in the subsequent Education Acts (1996, 2002, 2005 and 2011), with the objective of increasing flexibility in the curriculum, and to encourage greater autonomy and diversity in the education system in order to raise standards for all.

Second World War, in response to the need for a better-educated workforce (Jeffereys, 1984), the Butler Act had introduced a distinction between Primary (5–11) and Secondary education (11–15). For the first time, free Secondary education was provided for all students. The school leaving age was increased to 16 years old in 1972.

The 1988 Education Reform Act set the basis for the introduction of a National Curriculum. Such a National Curriculum would establish a compulsory set of subjects for State-funded schools, as well as certain standards that learners should achieve in each subject. Mathematics, English and Science were designated as core subjects. The idea behind the creation of a broad and balanced National Curriculum was to make sure that all students received a common basic education. The Education Reform Act decreed that the National Curriculum would be organised into blocks called 'Key Stages' (KS). Two key stages were stablished for the Primary school –KS1 and KS2– and two for the Secondary school –KS3 and KS4; the latter was divided into Years 7, 8 and 9 (from age 11 to 14), and Year 10 and 11 (14–16), respectively[28].

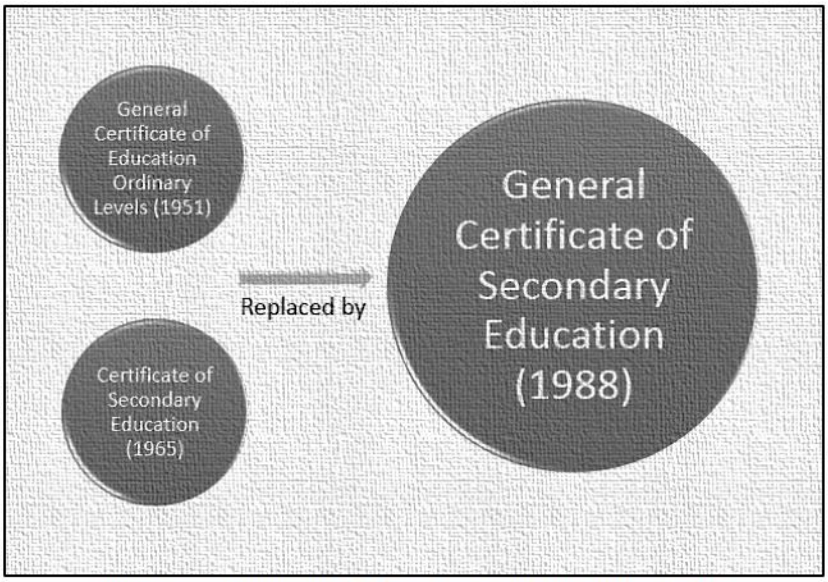

Figure 4.5. Changes in the KS4 assessment system in the UK.

At the end of each key stage, students' skills, knowledge, and understanding is formally assessed. The establishment of the National Curriculum Assessment was another of the novelties in the 1988 Act. At KS4 (age 16), the assessments were made with the so-called General Certificate of Secondary Education (GCSE) exam. The GCSE was introduced after many years of controversy and debate over the desirability of introducing a single KS4 assessment system. The introduction of the GCSE aimed at the creation of a single examination system in

[28] For the equivalence with the Spanish Secondary school stage, see Table 4.2.

the UK for pupils aged 16 and over. The GCSE was not seen just as a change of name with respect to previous examination systems (Figure 4.5), but as a fundamental curricular development.

Through a series of statutes and laws, the British system has been incorporating a typology of schools that has culminated in the configuration of a much more varied landscape than that of Spain. A first distinction can be made between state and non-state schools. The first are publicly funded, either by the central government or by the local authorities (LA). State schools are run by governing bodies that may depend or not on the LA. Within this broad category, we find numerous variants, which include Academies, community schools, foundation schools, free schools and voluntary schools. In terms of eligibility policy, we find comprehensive school and grammar schools. On the other hand, non-state schools (also known as 'Independent') are owned and run by private entities and are funded through students' fees. Currently, the percentage of students who attend independent schools in the UK is about 7%[29].

4.6. School-C

School-C is an independent, International Secondary school (from Year 7 to Year 11), located in a small town in the countryside close to the city of Cambridge (UK). A vast majority of the students come from the city. Cambridge has almost 130,000 inhabitants, of which 20% are student members of its well-known University. The number of high-tech companies –focusing on software, electronics, and biotechnology–has increased over the last few years, attracting many professionals from these sectors. This makes Cambridge a place with very specific demographic characteristics, which have a huge impact on schools. To start with, 41% of the Cambridge population has some higher education qualification, which is twice that of the national average[30]. Besides, many of these professionals are international, so there is a very high ethnic variety in the city, which is reflected in the classrooms. School-C has an enrolment of about 200 students from more than 40 different countries, distributed in classes of up to 16 people.

Being an Independent school with a student fee of around 13,000£ per academic year, the socio-economic profile of the students in School-C is quite homogeneous. Most of the students come from families settled in the local area, with a professional and business background. However, there is also a significant number of students who pursue short-term programmes, because their families stay in Cambridge for a short period; this translates into a

[29] Data taken from https://www.gov.uk/government/collections/statistics-school-and-pupil-numbers

[30] Data taken from https://cambridgeshireinsight.org.uk/wp-content/uploads/2017/10/Cambridge-City-District-Report-2011.pdf

very changeable student body from one year to the next, which, according to the head of studies, is a challenge for everyone.

On the other hand, as it is defined as a non-selective school in terms of students' performance, the academic profile of the School-C members is varied. For instance, among the students of the groups with whom I was conducting my observations, there were a couple of high-ability students and one student with special educational needs. They all followed the same lessons, but sometimes had to do some extra or differentiated work.

As we saw in the previous section, independent schools in the UK do not need to pursue the National Curriculum. In KS3, students in School-C follow the Cambridge Assessment International Education Secondary Curriculum for the sciences subjects. After Easter, Year 9 students must do what Christian – the participant teacher from this school– calls 'a checkpoint exam'. This exam is conceived to help the students –and also their parents and the teaching staff– to make the best strategic decision about the different Science options at GCSE level. Once in KS4, School-C offers the students the opportunity to follow the Cambridge International General Certificate of Secondary Education (IGCSE) in Biology, Physics and Chemistry, either as a Separate (Triple) Biology, Physics and Chemistry IGCSE, or as part of Coordinated (Double) or Combined (Single) IGCSE[31]. In 2018 (year of my fieldwork), six students had chosen to do the Triple Award Science, seven students did the Coordinated Science GCSEs, and only one opted for the Combined Science qualification. These students were distributed in different groups, depending on the programme chosen. Different teachers took charge of the different groups, depending on their speciality.

This "*calm, relaxed and wonderful place*" –in Christian's words– opened its doors 12 years ago, and since then, "*it has suffered numerous ups and downs*". Thus, although during its

[31] Unlike what happens in Spain, where at the end of the Compulsory Secondary stage all students must have passed the same number of subjects (although some of these may vary, since they are electives), in England students can decide -guided and assisted by their parents and teachers, and based on their interests and aptitudes- the number of GCSE exams they want to take to get their certificate. In Science, students have three different options: 1) to study Biology, Physics and Chemistry and end up with three GCSEs -the Triple Award Science, sometimes known as 'Separate Sciences' or 'Single Sciences'-; 2) to study all three aforementioned sciences within a cross-referenced syllabus and end up with a double award qualification (equivalent to two GCSEs) – the Double Award Science, also known as 'Co-ordinated Science'-. Most GCSE students in England follow the Double Award course, which covers approximately two thirds of the content covered by Triple Award Science students. They are awarded two GCSE grades based on their overall performance across all three science subjects; and 3) to study Biology, Chemistry and Physics within a cross-referenced, scientifically coherent syllabus and end up with one GCSE – the single award or 'Combined Science' qualification. This system was introduced in 2006 in the UK, and from the beginning, students in School-C were offered the three alternatives.

first decade of life, School-C did not stop growing and expanding, both in the number of students and facilities, in the last two years the situation changed drastically. In informal conversations with Christian and other staff members, they pointed to a change in the school's governing board that took place on September 2017. Whatever the cause, the data reveal that, for example, between 2016 and 2018, the number of Year-11 students enrolled in science subjects dropped from 58 to 15. This has, according to Christian, a positive and a negative side. The positive is that "*so small class sizes ensure that we [teachers] can give students all our best to guide and prepare them for their IGCSE exams*". However, for the school, the loss of students translates into a decrease in the funding and the available resources, so the management body had to dismiss some teachers and reorganise the remaining staff. Because of this situation, Christian, whose speciality is Chemistry, had to adapt to also teach Biology, Physics and Mathematics, with a corresponding decrease in his confidence as a teacher due to his lower subject matter knowledge.

4.6.1. Christian's case

CHRISTIAN	YEAR 7	YEAR 8	YEAR 10-C	YEAR 10-P
CLASSES	4h/w	2 h/w	2h20'/w; 2h/w	2h/w
No. OF GROUPS	1	1	2 (Triple; Co-ord.)	1 (Co-ord.)
No. STUDENTS/GROUPS	6	6	7; 6	10
OBSERVED LESSONS	4 (Doub.Less)	6	6; 6	6
TOPICS	Neutralisation; Acids and Bases	Human reproduction; Measurement errors; Chromatography	Chemical reactions; Reaction rates	Heat conduction; Convection; Conductors and Insulators; Radiation; Thermometers
EXPLANATORY EPISODES	2	3	2; 2	7

Table 4.6.1. Details about Christian's observed lessons.

4.6.1.1. Description of classroom context and teaching

Christian is an experienced teacher whose professional career has not been exempt from twists and turns. After finishing a degree in Environmental Chemistry, Christian spent a whole year travelling around Asia. This allowed him to learn new languages and get immersed in different cultures. Upon returning from his gap year, Christian enrolled in a Secondary Science PGCE course. Although at the beginning he *"really enjoyed the course"* and the idea of becoming a teacher was *"highly inspirational*", Christian started feeling "*overwhelmed and somehow out of place*" (I-Ch), so he decided to withdraw. After spending a few years working in various positions not directly related to his degree, Christian attempted to restart the PGCE, and this time he succeeded without major setbacks[32].

Already with the Qualified Teacher Status[33], Christian spent two years working in a *huge* state-funded school in London. This gave him some valuable knowledge and self-confidence. Besides, it made him realise he had made the right decision to resume the teaching path. Upon hearing of an offer for a science teaching position in a brand-new independent international school near Cambridge, Christian decided to apply, moved by his desire to experience different cultures. Since he got the position, more than 11 years ago, he has continued working in the same school, which he loves and where he feels very happy*, "although not everything has been a bed of roses*" (I-Ch).

Christian's teaching responsibilities have varied over the years. He began delivering exclusively Chemistry classes, but nowadays he also teaches Science (Y7), Physics, Biology and Mathematics. As I noted in the previous section, the fact that Christian has more subjects to teach today is motivated by a drastic decrease in the number of students enrolled in School-C (none of the lessons I was observing exceeded 10 students), which forced the management team to fire some teachers and reorganise the schedules of the rest. These difficulties they had to face together have contributed, according to Christian, to "*strengthen the group feeling*" among the remaining teachers. To his teaching responsibilities, we must add that Christian is the current head of the Science Department, which consists of three teachers (specialised in Physics, Chemistry and Biology, respectively) and one laboratory technician, Carla. Carla is, in Christian's words, "*one indispensable pillar*" of his classes.

If I had to use a single word to characterise Christian's educational setting, it would be 'diverse'. There is a diversity of spaces within his classroom, with a core of desks placed in three rows and others forming an L-shape; benches fully equipped for laboratory practices, a table for demonstrations and a reading area. Even the patio could be considered an appendix of the classroom, since Christian utilised it several times to perform some potentially slightly dangerous experiments that the students did observe through the windows. There is diversity in the type of activities proposed, which makes Christian's lessons very dynamic and non-monotonous. And diversity, also, in the instructional materials and resources used in the various

[32] Christian gave explicit consent to the publication of this level of personal information for academic purposes, after having been informed that this might enable his identification.

[33] This is the professional qualification required to take up a teaching position in England.

tasks, ranging from textbooks to quite sophisticated experimental devices, by way of tablets, scientific journals and even kitchen tools.

The second feature that caught my attention when I got into Christian's classes was the excellent relationship that he seems to have with all his students. Christian himself recognises that "*the first step to becoming a good teacher is to be a close teacher. If you don't genuinely care about them as individuals, if you keep distance, you lose them*" (I-Ch). Christian admits that one of the biggest challenges he must face as a teacher is to find the way to get students motivated, and that they *"do not lose that motivation as the academic year progresses*". Christian believes that, other than closeness, his sense of humour may help him to overcome this challenge, by making the school "*an enjoyable place where students can keep in a good mood and a good disposition towards learning*" (I-Ch).

This good relationship with his students, along with Christian's conception of teaching, favours the creation of a learning environment where everyone feels comfortable and confident enough to take part in any activity and to express their ideas; this is fundamental because, in Christian's lessons, students are continually engaging in small-groups and whole-class discussions and dialogues on the issues at hand.

In these dialogical exchanges, it is common that Christian launches a string of questions to the students, who in turn have the freedom to ask questions as well. Through these questions, Christian aims to gauge the degree of involvement of the students and their level of understanding, as well as having access to their ideas regarding the topic they are dealing with. Usually, these questions do not have a single response. However, there are times when Christian's questions probe for a specific answer. In the latter cases, if a student does not know the required answer or she is wrong, Christian does not immediately provide the correct one. Instead, he gives the student some cues so that she can relate the question to something she already knows, or he invites other students to propose alternative solutions.

Christian sees himself as a facilitator, "*a guide*". He is the one who "*plans, proposes and sequences both the content to be taught and all the learning activities",* but he firmly believes i) that the students are the real protagonists of the process of knowledge and skills acquisition, and ii) that they learn "*by doing and by making mistakes*". The point on which all Christian's science lessons revolve is "*the interaction (of students) with phenomena",* something that sometimes *"even precedes concept acquisition*". He considers this is "*the best way to promote student thinking*", which is, according to him, "*the aspiration that every teacher, especially science teachers, should have"* (I-Ch). Positioning, then, phenomena as the starting point and the promotion of thinking abilities as his final goal, it is not surprising that Christian tries to engage the students in a varied assortment of scientific practices. This includes prediction formulation, explanation construction, experimental design, observations and data collection, and data interpretation, among others.

Enrolment in scientific practices and experiencing phenomena which are related to the course content plays, then, a leading role in Christian's classes. This allows him to work on numerous learning dimensions at the same time. Thus, when students are immersed in these practices, Christian introduces or reinforces conceptual content, but he also endeavours to foster the development of other cognitive and/or manipulative skills, including:

i) Observation skills. For Christian, it is important his students become aware that "*systematic and careful observations are the first step for the construction of scientific knowledge*" (I-Ch). That is why whenever they perform an experimental activity, Christian asks his students to take note of what they have observed[34];

ii) Reasoning skills. This term is used here to denote "the kinds of processes that students are asked to use to manipulate information, arrive at conclusions, and evaluate knowledge claims" (Piburn and Sawada, 2000, p.37). Within this category, we find not only the domain-general skills of analysis, evaluation, and synthesis but also a much wider range of thinking skills that includes problem-solving and creative thinking (Matthews & Lally, 2010). One way to prevent students from excessive rote memorisation is to cultivate their reasoning skills. Christian argues that if they can organise and establish connections between –and to make sense of– different pieces of knowledge, they will find it much easier to solve the problems and tasks raised, without needing to depend entirely on their memory;

iii) Reflective skills. In our interview, Christian acknowledged that he would love the students "*to ask many more questions and wonder more things than they usually do. Because if they asked more questions related to the phenomena we study, we would progress much more. Both pedagogically and scientifically*" (I-Ch). One way Christian has found to encourage his students to be critical and curious –and, therefore, to pose more questions– is to make them think about what they do, what they believe, and what they know. That is, Christian strives to

[34] Christian requires students to document their observations in their workbooks when he wants them to get engaged in a complete cycle of Prediction-Observation-Explanation (POE) (Furtak & Ruiz-Primo, 2008; Shemwell & Furtak, 2010). Following the POE instructional sequence, the students predict what they think will happen before conducting the activity. Once the procedure is finished, they write their observations down. Finally, Christian asks the students to explain why what they observed had happened. The POE approach is one of the instructional strategies used by Christian to teach students how to build high-quality scientific explanations.

propose experiences that require reflectivity. Reflectivity is characterised by Alexander (2017) as "the deliberation, pondering, or rumination over ideas, circumstances, or experiences yet to be enacted, as well as those presently unfolding or already passed" (p.308). This is what Christian demands of his students when they finish an interactive activity: "*Two minutes to reflect about what we learnt so far about the uses of a range of acids*" (Y7.O3.S-Ch).

Christian's learning objectives reflect his scientific interests. Christian defines himself as an optimistic –"*I am convinced that we've still got time to save the world*" (I-Ch)– and curious person who loves science in all its dimensions. He feels very interested both in its history and its applications. Although he declares some ignorance in this regard because he has never been a full member of the research community, he also likes to keep informed about how science works and how it evolves. He believes that this is something that should be transferred to the classroom. On numerous occasions, Christian takes the opportunity to introduce how scientific knowledge is being built throughout history. This, in turn, allows him to introduce some aspects of the nature of the scientific enterprise. For example, the possibility of obtaining different values when collecting data – "*So, lots of different measurements, lots of different accuracies, and it depends on the calibration equipment, maybe? But also, on the human error, because it's easy to make mistakes, isn't it? That's life*!" (Y8.O1.S-Ch); and the necessity of establishing agreements, albeit arbitrary –*"Dr Celsius decided to say 'well, the boiling point of pure water, I'm gonna call that 100; I'm gonna call the freezing point of water, zero'. That's what he decided"* (Y10.O2.P-Ch).

Regarding assessment, Christian admits it is an area in which he feels certain tension between what he would like to do and what the system pushes him towards. There is a pressure from which he would like to escape, which is the one imposed by the national exams in Year 11. His students have internalised the idea that these national exams will have a decisive weight in their future (something in which, he suspects, parents have much to do with). Although it is not the norm, "*some students become so obsessed with it that they neglect other, more important aspects of their learning*". For reasons like this, Christian "*would love them to forget the exams. I want them to learn to learn (…) because that's very useful in life, more than chemistry or physics"* (I-Ch).

Another important aspect for Christian is his students "*get involved in the assessment process*" in different ways because that, he believes, "*may contribute positively to their learning*" (I-Ch). That is why during his science sessions, Christian generates opportunities for students to assess their work and that of their classmates. Besides, he tries to make sure that the students do not develop a negative relationship with the processes of assessment and marking. To avoid this, when he has to evaluate an activity, a task, or an answer, Christian uses a very positive and encouraging language, which might help the students understand "*what it is expected from them, at what point in their development they are and how they can improve*" (I-Ch). This fits with the previously described objective of developing reflective and metacognitive skills: *"[We] need to fill the review sheet at the end. What we need to put on the review sheet is* ***what you did well on, what you need to improve on, and what you enjoyed the most****. Think about it and write it down."* (Y8.O2.S-Ch)

The diversity to which I alluded at the beginning of Section 4.6.1.1 is also present in the assortment of methods and tools that Christian uses for assessment. During the time I was with him, Christian used, for formal assessment, multiple-choice tests, mock exams, posters-making, group work, homework, hands-on activities, science projects, worksheets and explanation-writing. Informal methods included observation, prediction-telling, student self-evaluation, questioning, the plenary grid, classroom discussions, computer games, quizzes (Kahoot®) and skills checklists. This plurality seems to summarise Christian's belief that "*learning is a tremendously complex task.*" (I-Ch).

4.6.1.2. Christian's PCK of Scientific Explanation. Introduction

In the following sections, I present and analyse Christian's PCK of scientific explanation (summarised in Table 4.6.1.2a). Christian[35] seems to have as a goal that his students learn how to build good explanations using scientific knowledge. Because of this, he consistently used one practice-specific instructional strategy to provide support for explanation crafting. Moreover, he also asked his students to write their explanations in their workbooks so that he could assess them in the future. All this makes Christian a highly interesting case to analyse, according to my research purposes.

Among Christian's lessons, there are many complete episodes that are appealing and illuminating to understand his PCK of scientific explanation. I have selected one of them to be displayed as a vignette (Table 4.6.1.2.b).

[35] It should be reminded that Christian had previously been a participant in my pilot study.

<table>
<tr><th colspan="4">CHRISTIAN</th></tr>
<tr><th colspan="4">Orientation Toward Science (OTS)</th></tr>
<tr><th>Knowledge/beliefs about the goals of science</th><th>Knowledge/beliefs about science teaching and learning</th><th>Teaching practice</th><th>Knowledge/beliefs about Scientific explanation</th></tr>
<tr><td>· Scientists as explanation-seekers.
· Science might reveal fundamental answers
· Connection between science and technology</td><td>· Educational goals: to develop cognitive and/or manipulative skills (Observational, Reasoning, and Reflective skills)
· Teacher as a facilitator, a guide
· Students must be cognitively active while engaged in different practices and activities</td><td>· Practice-based
· Student-centred
· Interrogative approach
· Dialogical approach</td><td>· Search for explanations → privileged place within scientific enterprise
· Two meanings for explanation: causal account and justification</td></tr>
<tr><th colspan="4">Knowledge of Instructional Strategies (KIS)</th></tr>
<tr><th>Communicative approaches</th><th>Activities</th><th>Language devices</th><th>Interaction patterns</th></tr>
<tr><td>·Interactive/ Dialogic (12)
· Interactive/ Authoritative (4)</td><td>· Specific activities to build explanations
· Whole-class dialogue
· Pair discussion
· Explanation writing
· Hands-on activities
· Book-based & video-based activity
· Demonstration (with questioning)</td><td>· Direct instructions
· Questions · Examples
· Demonstrations/ Experiments
· Prompts · Keywords
· Motivational statements
· Summaries
· Repetitions · Checking for agreement/ disagreement</td><td>· IRE(F)P complex sequences
· Student-student interaction
· Group sharing
· Student interventions sequences · Hesitations and pauses
· Question – Answer
· Spontaneous interventions
· Alternation with interruptions</td></tr>
<tr><th colspan="4">Knowledge of Assessment (KAs)</th></tr>
<tr><th colspan="2">Dimensions to Assess</th><th colspan="2">Assessment Methods</th></tr>
<tr><td colspan="2">· Multiple dimensions
· Conflict with formal assessment (National exams)
· Products and effort</td><td colspan="2">· Peer-assessment and self-assessment
· Informal assessment of students' explanations → verbal feedback, questioning
· Possible written feedback</td></tr>
</table>

Table 4.3.1.2.a) Summary of Christian's PCK of Scientific Explanation.

Table 4.6.1.2.b) Vignette #1. Example of explanatory episode in Christian's observed lessons.

TEACHER	***CHRISTIAN***
VIGNETTE/EPISODE/ OBSERVATION	***V#1 / E#4 / Y10.O1.P-Ch***
TOPIC	***Convection***

Ch.- Now, draw a quick picture here, so now we've got a piece of material like that, and another piece of material, like that, ok? So, I put an ice cube on the top of it, there's our ice cube. Ok, now, this one feels cold. The surface feels cold, yeah? And what he said about this one? Just it doesn't feel cold. Surface feels cold here, surface doesn't feel cold. So, this one, definitely feels cold, this one doesn't. They are the same temperature, but this one definitely feels cold and this one doesn't feel cold. I think he said this one was heavier and this one was lighter? Ok. Heavier material, and this one is lighter material. They look quite similar, both are dark. Draw an ice cube on top… ice cubes melting. (…). They are no longer on the freezer. Now, let's make a prediction. Same shapes, same length, same depth… the ice cubes you are using are the same size, as well. We need to make a prediction, guys. So, they are going to melt, right? The kitchen is not below zero, right? It's comfortable, it's 20 degrees. So, the ice cubes are gonna melt. So, either they are gonna melt faster one or the other, or they are gonna melt at the same rate. And if they melt faster one or the other, which one is gonna melt faster? This one feels cold, this one doesn't feel cold. It's the only difference, really. Ok, well, this one was heavier, this one over here is lighter. So, what do you reckon, guys?
S1.– Would it be that the one that doesn't feel cold…
Ch. – It does what?
S1.– The ice melts quicker in that one.
Ch.– Ok, so you think that the one that is on the surface that doesn't feel cold melts quicker. What about you, Carla? You say that this one melts quicker… Claude?
S2.– The right one.
Ch.– This one will melt quicker? [E-FN: pointing to one of the drawings].
S2.– Yes.
Ch.– Ok. Chase? Same melting? Or if they have different rates, which one melts quicker? This one? The one that doesn't feel cold will melt quicker? Ok. So, at this moment, we've got 1,2,3 people… well, no, 6 people who say that the one that doesn't feel cold is gonna melt quicker. One person says that the one that feels cold will melt quicker. Now, Chase, why do you think that this one is gonna melt quicker?
S3.- Because it doesn't feel cold, and it should in a way says it's warmer, it's because [inaudible] some heat on it. And… that's all, I don't know.
Ch.– Ok. Thank you very much. And, Claude, what about you? You said that the one that feels colder will melt quicker.
S4.– Because that's a better conductor heat.
Ch.– Ok, ok. And what makes you think that is a better conductor heat?
S4.– Ahm…, it feels colder and heavier, so, it seems like it is a metal.
Ch.– So, metals, in your experience, feel colder, yes? So, this is at the same temperature than this, ok? Feel the metal, hold it, feel the plastic. (…). This feels cold, yes? So, Claude says that, in his experience, the metals feel colder, and they are better conductors, so he thinks this one melts better. Ok, fair enough. So, different perspectives. This one feels warmer, so, there is more heat in it, so the heat will get into the ice cube. Yes? Ok!

Table 4.6.1.2.b) Vignette #1. Example of explanatory episode in Christian's observed lessons.

TEACHER	*CHRISTIAN*
VIGNETTE/EPISODE/ OBSERVATION	***V#1 / E#4 / Y10.O1.P-Ch***
TOPIC	***Convection***

(…) [The video goes on]
Ch.– Can you try to explain that? So, if we write down what happened, yes?... Ok, so, the ice cube on the surface that feels cold melted much quicker, that's what happened. That's the observation, yeah? 'The ice cube on the surface that feels colder melts quicker'. Ok? Why? What are the key words here? What are the key words that we need to put into our explanation?
S4.– Energy.
Ch. – Thermal energy, that's good. What else?
S1– Insulator.
Ch.– Insulator.
S2.– Conductor.
Ch.– Ok.
S3.- I'm not sure how to write the explanation.
Ch.– We're gonna write it, but before we do, we're gonna put down some key words that we need to put in there. Now, when you are sitting on a metal fence on a cold day, you feel it cold. If you sit or rest on a wooden fence, at the same temperature, it doesn't feel cold. So, your body is at about 37 degrees, the outside is about 5 degrees cold, and the heat from your body goes to the inside of the metal so quickly.
Ch.– It's not going into the wood, because the wood is an insulator, ok? So, materials that are conductors, will take the temperature difference, so they will move the heat energy across from the area […]. All right? So, what are the key words here? Thermal energy, insulator, conductor…
S3.- Metal.
Ch. – Yeah, we've got metals! If we put 'metals', we could put 'plastic', 'wood', yeah, things that are insulators. Anything else you think it's key for this explanation? Because, you're gonna have two minutes to write an explanation about this phenomenon. Do you think we need anything else?
S4– Transfer?
Ch.– Transfer, ok… it's about how energy is transferred, so you'll need to be using the word 'transferred'. That's good, yeah! That's all? Fair enough! Then, two minutes to put in paper why this one melts quicker. If you want to explain it really well, then include those words. Your two minutes start now. (…).
What you're gonna do, you're gonna read out your explanation so far to the person sitting next to you, ok? So, you've got to take turns for listen, and then, read yours. (…).
Now, having listened to someone else's, is there any way you think you could improve yours? Something you could add to yours? You've got one minute to add something that, after listened someone else's explanation, you say 'Oh, I like that!', or 'I wanna use that word'. You've got one minute to improve your explanations.
(…)

4.6.1.3. Orientation Towards Science (OTS): Christian's knowledge and beliefs about Scientific Explanation

In Section 4.6.1.1, I described Christian's context and teaching style in an attempt to capture his practice-based orientation. In this section, I detail some ideas and beliefs Christian holds about science and scientific explanation, to try to relate them to the strategies deployed and the assessment models used in the explanatory episodes observed.

Something that puzzled me about Christian is that, although with his students and in our informal conversations, he seemed confident and talkative, during the interview, he was quite reserved and even elusive. He was, in fact, the only participant who did not reply to some of the questions I posed because he was not sure what to say. Nevertheless, Christian was sincere and reflective. For example, when I asked him for a personal characterisation of science, he said: "(h)*onestly, I don't think I'm capable of answering or defining what science is*". To facilitate the task, I reformulated my wording and asked him what he believed the objectives of scientists are, to which Christian replied:

> *"Mmm…, I think I can say that scientists fundamentally seek to explain natural phenomena, in principle. But I believe that, if we go deeper, what science is trying to reveal are the intimate secrets..., eh…, those odd questions that we always ask ourselves: whether the universe is infinite or not…, even if God exists or God does not exist… I think that's the final aspiration, to reveal that. In any case, it always has a practical side… I mean, whenever something is discovered, it always influences technology and ends up permeating through our daily life; that is, it is also important in that sense"* (I-Ch).

From this answer, we can extract some compelling ideas. First: Christian places the search for explanations in a privileged place within the scientific endeavours. Second: for Christian, science is powerful. It could lead us to unveil some of those 'secrets' that humans have been questioning about for centuries (whether there is anything to unveil would be the object of another full dissertation). And third: for Christian, there is a fundamental relationship between science and technology; scientific knowledge can always be applied to intervene and control our environment. These beliefs about science may have an impact on how Cristian teaches science. When asked to elaborate a little more in his statement and to explain what scientists do to achieve these objectives, Christian gave a very revealing answer:

> "*The most important activity that a scientist performs is not the routine of every day, that is, the laboratory routine. The most important activity that a scientist*

> *performs, I think, in my view, is asking questions. To be continually asking questions. Sometimes answers are not as important as questions*" (I-Ch).

In this fragment, Christian contrasts the most routine parts of the scientific performance with the most creative parts of it. Besides, his reference to a 'continuous questioning' points towards the dynamic nature of science. This statement might help us understand why Christian uses in his classes an interrogative approach to learning. In all the observed sessions, Christian poses questions to his students aimed at diagnosing, supporting, and expanding their ideas and their thinking. Students, in turn, are also free to ask as many questions as they want. More concretely, this questions-and-answers dynamic in Christian's classes has different teaching purposes, which include: 1) Recalling knowledge –"*What's the symbol for silver?* (Y10.O3.C-Ch); 2) Engaging students in the tasks –"*Which of these junctions would you put into the probe*?" (Y10.O2.P-Ch); 3) Checking understanding –"*Why does it turn blue? What does that tell you*? (Y10.O4.C-Ch); 4) Probing students' prior knowledge –"*Does anybody know the name of this? It's a common name* (Y10.O4.C-Ch); 5) Eliciting students' ideas –"D*o you think they all have exactly the same ability to give away electrons*? (Y10.O2.P-Ch); 6) Clarifying concepts –"*What does the word 'range' mean*? (Y7.O3.S-Ch); 7) Making students reason –"*Why is it acting as an acid in this particular reaction*? (Y10.O4.C-Ch); 8) Applying conceptual knowledge –"*What's the different between the way the glass is expanding and (how) the liquid (expands*)? (Y10.O2.P-Ch); 9) Focusing attention –"*You can see that there's a little bit of pink stuff there, can you see that?* (Y10.O4.C-Ch); 10) Bringing scientific knowledge to daily life –"*Does anybody know what you are supposed to do when you get stung by a wasp?"* (Y7.O1.S-Ch); 11) Checking agreement –"D*oes anybody disagree with that? Nobody?"* (Y10.O2.P-Ch); and 12) Making sense of procedures –"*Why are we gently heating it*? (Y10.O4.C-Ch).

Beyond these concrete purposes, the meta-objective that underlies Christian's questioning is that students remain cognitively active while they are engaged in different practices and activities. Maintaining dynamism without students losing sight of the task's goals is something Christian achieves thanks to his ability to accommodate his questions to students' contributions, and to react to students' ideas in a positive or neutral rather than evaluative manner. As a result, a working environment is created in which all students actively participate in the process of knowledge co-construction. This is exemplified in those episodes in which Christian proposes the elaboration of an explanation.

During my period of data collection with Christian, I observed 16 episodes on explanation out of 32 lessons. Although not too numerous, these episodes exemplify what researchers and educators understand by the implementation in the classroom of scientific explanation as a practice through which to make sense of empirically founded phenomena. In one of the lessons recorded for the pilot stage, he asked his students to "*use science to explain it. Science that we have already learned, and we put into practice*" (Y8.PO6.S-Ch). When I directly asked him what a scientific explanation is, Christian characterised it as a fundamental scientific *activity* in which *ideas* (knowledge) *and words* (language) are used in a specific manner to give an account of *why something happens* (I-Ch).

Out of the 16 episodes found, more than a half (nine) can be labelled as 'scientific explanation'. And what I find more interesting: from these, eight episodes are activities in themselves. That is, Christian, proposes activities whose main goal consists of building an explanation for a phenomenon that the students observe (either because they experience it, or because Christian demonstrates), or that they have previously studied. Christian devotes a lot of time to these activities of explanation construction, since they are usually the culmination of a set of tasks structured around the same goal or concept. For example, Episodes #4 and #10 take place over two lessons.

In many explanatory episodes, Christian and his students use mechanistic reasoning patterns; that is, they appeal to unobservable entities, their properties, organisation and behaviours, to explain observable phenomena (Machamer *et al*., 2000) –"*What is it about the structure of a gas, of the particles in gases?*" (E#5-Ch). In Episode #10, Christian uses a language with anthropomorphic connotations within his mechanistic explanation (see Table 4.6.1.3). This might be because, for Christian, the formulation of explanations is both a means and an end, so he never loses sight of its didactic value.

Despite being quite consistent in his conceptualisation of scientific explanation, Christian makes use of other meanings of explanation that emerged throughout this research. Specifically, he uses 'explain' as a synonym of 'justifying actions, propositions and/or beliefs'. Within this category, we find examples in which students justify their answers (E#9-Ch; E#11-Ch; E#6-Ch; E#4-Ch), certain result (E#8-Ch; E#12-Ch; E#15-Ch) and/or an experimental procedure (E#13-Ch).

In Christian's lessons, it is the students who mainly do the reasoning needed to build and refine the explanations. He gives them some clues, guides them through questions, and corrects them at times, but the weight of the construction is on the students. Christian appreciates and values the effort that students must make to explain a phenomenon, and this is something he tries to convey to his students.

> *Ch.–Can anyone describe how is the conduction process happening? Anyone be brave and have a go! Claude.*
>
> *S2.– Mmm, vibration gives heat, ahm…, gives more energy to the particles, so they vibrate more, and the vibration causes (…).*
>
> *Ch.–* ***Very good effort at explaining***. (E#2-Ch).

Another aspect that characterises Christian regarding the introduction of this epistemic practice in the classroom is that he repeatedly asks the students to write the explanations that have been co-constructed in the class in their notebooks – "*Bubbles arise in the second test tube. And the question is why? So, we're gonna ask you to write a little explanation."* (E#7-Ch). Writing an explanation is an individual task that requires concentration and ability to reason, to structure ideas and to use language properly to express them; one student cannot delegate responsibility on this task to another peer or to the group. Christian leaves enough time for students to write their explanation, which facilitates longer, more elaborate, and more complete accounts than what would be obtained with merely a verbal construction. Besides, putting an explanation in writing makes possible its evaluation and improvement, both by the student and by Christian.

In several episodes, Christian refers to the quality of the explanation and he even has a strategy for students to enhance their explanations, as we will see in the next section. In Episode #4, he asks the students '(a)*ny other things that would make us construct a good explanation?'* (E#4-Ch), which indicates that Christian has a model, albeit not necessarily formal, of the standards of adequacy of this practice (Brigandt, 2016). That he insists students should write the best version of their explanations indicates, also, that for Christian it is important that they are aware that this is a practice in which they may achieve different degrees of proficiency. That students know that Christian will assess the explanations included in their workbooks may influence the way in which they approach the task. This claim is in line with Berland and her collaborators, who state that students adjust their engagement in classroom activities depending on who their potential audience might be (the teacher, an external examiner, their peers), and how they perceive the audience could use their knowledge product (Berland *et al.,* 2016).

Table 4.6.1.3. Different meanings of 'explanation' found in Christian's observed lessons.

TYPE OF EXPLANATION	***EXAMPLE***
SCIENTIFIC EXPLANATION	**Articulation of theoretical and background knowledge to make sense of a certain phenomenon through a process of reasoning**
Causal/ Mechanistic	*Ch.– So, which is better conductor: liquids or gases?* *S2.– Eh…liquids.* *Ch.– Liquids, yeah! So, solids, that's where conduction happens, you know, faster. Liquids are not really good at conducting, and gases are even worse. Yeah? And why is that?* ***Why is it that gases are even worse at conducting heat? What is it about the structure of a gas, of the particles in gases?*** ***S3.– They spread very far****.* *Ch.– Excellent. Gases are even worse at conducting heat. So, it's all about transferring these vibrations from one particle to the next, and in gases, they spread so far apart that it's even slower than in liquids. In gases, conduction still happens, but very slow*. (E#5-Ch)
Anthropomorphic	*Ch.– There's something else with temperature that has a much bigger effect than just increasing the number of collisions.* *S1.– I'm not sure, but, because there's more temperature, they have more energy to pass… so, because to make collisions successful for the reaction there has to be a certain amount of energy…* *Ch.– Ok, let's talk about this again, right? So,* ***if they miss each other, there is no chance of reaction****. If they hit each other with not enough energy, they don't react. But if they hit with enough energy, they will react.* (E#10-Ch)
NON-SCIENTIFIC EXPLANATIONS	**Justifications for actions, propositions and/or beliefs**
Justifying an answer	*Ch.–* ***What makes you think that's a good answer?*** *S1.– Water is one of the only neutral substances.* *Ch.– Great answer! Very good, that's excellent.* *S2.– Because if you have water you need hydrogen, which is H, and Hydroxide, which is HO, which is what makes something acid and what make something alkali… so, if you add and acid to an alkali to make it neutral, then, the H and the HO combine in H2O.* *Ch.– That is a great answer. That's a fantastic answer. He knows that water is H2O, he knows that acids got H, he knows Hydroxide is OH. If you put H and OH together, you get H2O. that's a great answer. Very, very good*. (E#9-Ch)
Justifying a result	*Ch.– Now, the question is:* ***why are they not all the same?*** *Yes? So, what we've got? My walk took the same amount of time, but they are all different. I mean, the only ones that are the same are these two, but nothing else is the same, isn't it? You have a whole minute to try to discuss why they are different.* *S1.– Possibly, because we didn't start at the same time and stop differently, too* *Ch.– Yeah, absolutely right. Fantastic answer. Anything else, apart from that? So, different reaction, because start differently and stop differently. Or the devices could be wired differently, we calibrate them differently*. (E#8-Ch)
Justifying a procedure	*Ch.– In here it's just neutral. Can you see that? How do we now get dry pure crystals of sodium chloride? From this.* *S1.– Filter.* *Ch.– We don't need to filter anything! Not in this one. We did in the other one, because it was an insoluble base. There's no filtering needed. You need to gently heat it.* ***Why are we gently heating it?*** *S2.– To evaporate the water.* *Ch.–* ***To evaporate the water, exactly! That's what we're gonna do, right?*** *So, you gently heat it, and then, you leave it on one side.* (E#13-Ch)

4.6.1.4. Christian's Knowledge of Instructional Strategies (KIS)

After analysing the data that I collected as part of a pilot study for my first-year report[36] –for which, among other things, I was observing Christian and his colleague Caroline for a week– I reported that "Christian deployed a wide range of language devices and instructional materials to support students' verbal explanation-construction, as part of a set of inquiry and hands-on activities" (§A.2). In that report, I did not delve into what these language devices and instructional materials were and what kind of support they provided to students in the process of developing explanations.

Before starting my thesis fieldwork in School-C, I decided to conduct a new round of analysis of the episodes recorded during the pilot stage. Several reasons motivated me to do this. First, I wanted to test the coding framework developed for this dissertation (§3.7), which differed from the codes designed for the pilot study. The second reason rests on my first impression of the data taken at School-A. When I started my analysis, I was initially a bit frustrated because I was not able to identify a single episode in which Adrian or Alba requested their students to elaborate a scientific explanation according to the operational definition I had developed for this research (§2.5.4). So, I thought the data collected in School-A were not going to lead me to any valuable conclusion. On the other hand, in just one week with Christian in June 2017, I had witnessed two episodes that might help me find some answers to my research questions. In order to have more data for my thesis, then, I decided to re-analyse what I have gathered during the pilot stage; this time, under a better-defined conceptual framework.

The second round of analysis revealed that Christian made use of a practice-specific sequence of instructional moves in two episodes of explanation construction. I was concerned about the possibility that Christian had designed this teaching strategy just to be implemented the days that I was observing his lessons. However, the way in which the students got engaged in the work, together with the quality of the produced explanations, made me think it was not the first time they had to explain an observed phenomenon. Christian deployed the same teaching sequence during the five-weeks observations I conducted in 2018. Again, the students had a very positive response to it, which reassured me that articulating explanations was a common practice in Christian's classes. His practice-oriented conceptualisation of science teaching and the predominance that phenomena play in his class also backed my belief.

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[36] The First-Year Report is an assignment that every student needs to submit as part of the first-year probationary assessment process of the University of Cambridge. In this report, the student must present a justified proposal for the doctoral research project she wants to conduct. The First-Year Report must be approved by a committee for the student to be allowed to register for her PhD Degree course.

Since Christian designed and applied a specific strategy to teach how to create explanations in the classroom, I found it interesting to inquiry into it in more detail, to understand the parallelisms that might be established with the PTDR model (Yao *et al.*, 2016) (§2.5.4). In three episodes (E#4-Ch, E#7-Ch and E#10-Ch), Christian's presentation of a specific phenomenon is the starting point of an explanation activity. In Episode #4, the triggering phenomenon is introduced with a video in which two ice cubes are on different surfaces, and one of them melts before the other; students must explain why. In Episode #7, a student holds a tube filled with gas connected to another tube that contains water, in which bubbles begin to form; students must explain why. Finally, in Episode #10, Christian projects a computer-made animation showing collisions between different particles; students must explain why increasing the temperature increases the rate of reaction. This first phase corresponds to the description of the phenomenon component of the PTDR model.

The second step of the sequence presents two variants. Either Christian asks the students for some keywords to construct the explanation, or he requests the students to discuss in pairs what a possible explanation for the phenomenon might be. In the second case, after the pair-discussion, the collection of keywords takes place. Students' keywords allude to theoretical concepts (e.g., thermal energy, conduction/convection, colliding theory), generalisations, and empirical facts (e.g., "*all of us, unless you are zombies or vampires, will have a body temperature of 37, which is warmer than the temperature in this room, which is approximately… 20ºC*" (E#7-Ch)). Christian usually complements the keywords with pictures on the blackboard and/or computer images. In the PTDR model, there are two components that are needed to build the explanation: data and theory. Both are present in Christian's approach to explanations.

Once the keywords have been selected, Christian establishes a dialogue with the students to give them some clues about how to build the explanation. Usually, he starts the process of connecting all the keywords to explain the phenomenon. Christian reminds the students of something they have said before about the phenomenon under study or the concepts involved. This whole process is accompanied by questions that Christian launches to steer the students towards the right direction. In this way, the class participates conjointly in the process of verbally constructing the explanation.

The next step is the writing of the explanation. Each student must construct a narrative of what they have been discussing in class. Christian makes some recommendations about how to write a good explanation –"*If you want to explain it really well, then include those words.*" (E#4-Ch).

The final step is targeted to enhance the quality of the explanations produced. Here, we also find two variants. In the first one (which was also observed in the pilot study), Christian matches pairs of students to read their respective explanations. Each student must listen to their classmate carefully to take some ideas that may be applied to her own explanation –"*if you listen to something that you say 'uh, I should include that', then, improve yours for a minute. So, read out loud taking turns.*" (E#7-Ch). Once this is done, some students share their explanations aloud with the whole class, highlighting those points they have changed after listening to their peers. In their study about pre-service elementary teachers' knowledge on explanation construction, Zangori and Forbes (2013) reported that many of the participants found it very fruitful for students to engage in iterative cycles of writing their explanations and then sharing them with the rest of the class. In the second variant (which only appears in E#10-Ch), students read aloud a model explanation from the textbook, so that they can establish some connections and comparisons with their own explanations.

In Figure 4.6.1.4, I display a graphic representation of Christian's instructional sequence for teaching how to build high-quality scientific explanations[37].

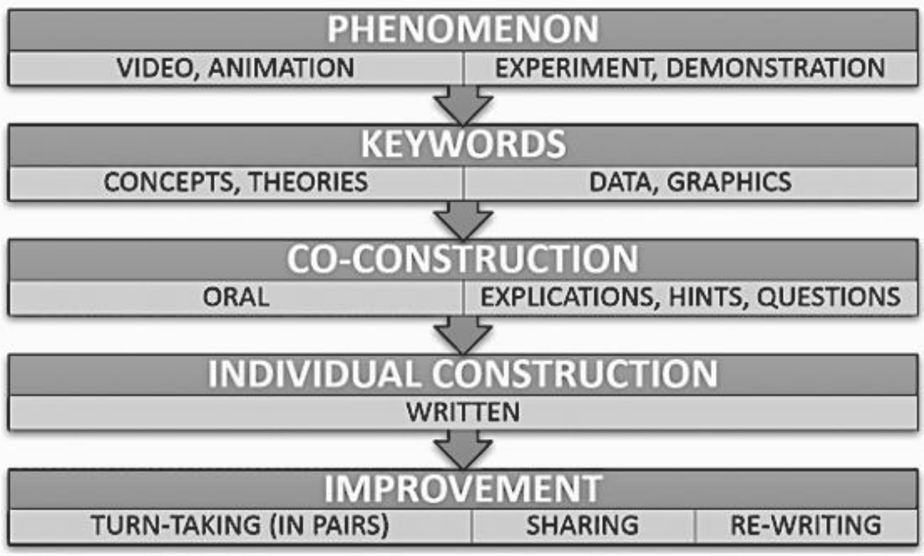

Figure 4.6.1.4. Christian's instructional sequence for teaching how to build a good explanation

As I have defended throughout this thesis, a primary source of information for understanding teachers' Knowledge about Instructional Strategies (KIS) comes from their communicative approaches and interactions with students, since the processes involved in the

[37] Christian uses the same teaching strategy for the construction of explanations in different classes for two different subjects: physics and chemistry. This may suggest that the same structural and functional model could be applied to different branches of science, despite the qualitative different patterns of explanation that characterises different domains (Keil, 2006). Further data would be required to test whether the effectiveness of the strategy was the same in both domains.

articulation of explanations are mediated by language and discursive norms. Christian's 16 episodes have an Interactive character (Mortimer & Scott, 2003). That is, the students are actively involved in the construction of the explanation in different ways. An overwhelming majority of these exchanges (75%) also has a Dialogic character. This is, in 12 of the 16 episodes Christian explores students' views about the phenomena under explanation and takes account of them. In these situations, Christian usually asks open questions aimed at eliciting the opinions and knowledge of the students (E#4-Ch), and gives them enough time to elaborate an answer (E#2-Ch). Although he guides the construction process, Christian lets the students propose, and inquire, into their own contributions (E#2-Ch). On the other side, we find four episodes that fall within the category of Interactive/Authoritative approach, because although Christian involves students through questions, these are closed and aimed to direct them towards a specific idea. In Table 4.6.1.4.a, I present an episode to illustrate Christian's Interactive/Dialogic approach, and one episode to exemplify the Interactive/Authoritative ones.

As I said in my description of Christian's teaching environment (§4.6.1.1), diversity is one of its most identifying characteristics. This diversity extended to the type of activities proposed. In the case of explanations, Christian proposes individual, group and pair-based activities. From another perspective, some activities are strictly oral (discussion, questioning, dialogue), others require writing, and others can be classified as manipulative/experimental (hands-on activities and demonstrations). From the 16 episodes, there are six in which the explanation seems to be an end, or, at least, one of Christian's learning objectives. In these six episodes, he puts into practice some specific instructional strategies for the formulation of explanations. In the others, the explanation is an intermediate stage or an accessorial part that Christian uses so that the students may understand or enhance some conceptual knowledge (E#2-Ch, E#3-Ch, E#6-Ch), understand a procedure/result (E#9-Ch, E#11-Ch, E#13-Ch), or understand some aspects about the nature of the scientific enterprise (E#8-Ch). The three episodes in which a student is requesting an explanation for a phenomenon have not been included in this section, since they are not part of any designed activity properly speaking (E#1, 12, 16).

In table 4.6.1.4.b, there are some examples by way of illustration for each of the types of activities of which the elaboration of explanations is included.

Table 4.6.1.4.a) Christian's communicative approach for the episodes on explanation

COMMUNICATIVE APPROACH	EPISODES	EVIDENCE
Interactive/ Authoritative	1; 12; 13; 14	*Ch.– Why are they moving at different speeds? Why are they moving at different speeds in terms of solubility?* *S1.–* ***Because of the acidity…?*** *Ch.–* ***No acids at all. What we are talking about is whether something or not something dissolves in water****. If it dissolves in water, is moving with the water. Have a look! Are the inks moving as fast as the water?* *S1.– No. (…)* ***Ch.– Are they the same solubility?*** ***Ss.– No.*** ***Ch.– Which is more soluble?*** ***S2.– The blue.*** *Ch.– Yes! So, what we're talking about is separating thing that are less or more soluble. Fair enough? (E#14-Ch)*
Interactive/Dialogic	2; 3; 4; 5; 6; 7; 8; 9; 10; 11; 15; 16	*Ch.– This one feels cold; this one doesn't feel cold. It's the only difference, really. Ok, well, this one was heavier, this one over here is lighter. So, what do you reckon, guys?* *(…)* *Ch.– Ok. Chase? Same melting? Or if they have different rates, which one melts quicker? This one? The one that doesn't feel cold will melt quicker?* ***Ok. So, at this moment, we've got 1,2,3 people… well, no, 6 people who say that the one that doesn't feel cold is gonna melt quicker. One person says that the one that feels cold will melt quicker.*** *Now, Chase, why do you think that this one is gonna melt quicker?* *S3.- Because it doesn't feel cold, and it should in a way says it's warmer, it's because [inaudible] some heat on it. And… that's all, I don't know.* *Ch.– Ok. Thank you very much. And, Claude, what about you? You said that the one that feels colder will melt quicker.* *S3.– Because that's a better conductor of heat.* *Ch.– Ok, ok. And what makes you think that is a better conductor of heat?* *S3.– Ahm…, it feels colder and heavier, so, it seems like it is a metal.* *Ch.– So, metals, in your experience, feel colder, yes? So, this is at the same temperature than this, ok? Feel the metal, hold it, feel the plastic. (…). This feels cold, yes? So, Claude says that, in his experience, the metals feel colder, and they are better conductors, so he thinks this one melts better. Ok, fair enough.* ***So, different perspectives****.* (E#4-Ch)
Non-interactive /Authoritative	----------	----------
Non-interactive/Dialogic	----------	----------

Table 4.6.1.4.b) Types of activities present in Christian's episodes on explanation

TYPE OF ACTIVITY	EXAMPLES
Whole-class dialogue	Ch.– So, Carlos, how is the heat reaching us from the Sun? because it's a long way away and it get here. S1.– Ahm… Ch.– Tell me letters or say the word. Or **nominate someone else in your group**… S1.– Radiation. Ch.– Radiation! Ok, thank you very much. It can't be conduction… Clemence, why is this? S2.– Because there is nothing to conduct. Ch.– There's nothing to conduct. Ok. It can't be convection, either. **Why not?** S2.– Because… there's not fluids… Ch.– There's no fluid between us and the sun, yeah? Apart from a very, very thin layer, the atmosphere, there is nothing. So, there's nothing to conduct, nothing to convect. So, it's this process call radiation, ok? (E#6-Ch)
Pair discussion	*Ch.- So, I have a question for you this morning.* ***To discuss in pairs****. So, you two, you two… 30 seconds, first of all. How does heat travel in solids? 30 seconds. (…). Ok, here we go. 30 seconds gone. So, how does heat travel in solids? [E-FN: dice].* *S1.– Mmm… conduction.* *Ch.– Conduction. Excellent, very good, well done. Can anyone describe how is the conduction process happening? Anyone be brave and have a go! Claude.* *S2.– Mmm, vibration gives heat, ahm…, gives more energy to the particles, so they vibrate more, and the vibration causes […].* *Ch.– Very good effort at explaining.* (E#2-Ch)
Teacher demonstration (with questioning)	*Ch.– Now,* ***we're gonna do a demonstration of gases****. So, there is a gas in this test tube, which is…* *S1.– Air.* *Ch.– Air. And that's a mixture, isn't it? What's in the mixture, Caroline? What gases are in the air?* *S2.– Ahm, oxygen, …, ahm, can't remember.* *Ch.– No problem. What is in there, apart from oxygen?* *(…)* *Ch.– Ok. Now, if we put that on there, and now, Claus, you now just put your hands on it, surround it, ok. Now, what's gonna happen as his hands… oh! You see that!? What did you see, Chan?* *S5.– A bubble.* *Ch.– So, Claus is making bubbles of here, ok? Did anyone see bubbles?* *Ss.– Yes!* *Ch.– (…) Claus's hands may be a bit warmer than most, because he got sunburned today, but all of us, unless you are zombies or vampires, will have a body temperature of 37, which is warmer than the temperature in this room, which is approximately… 20, ok. So, try to draw a diagram, and then,* ***try to explain that. Why are the bubbles coming out?*** (E#7-Ch)
Explanation writing (video + prediction + writing)	*Ch.-* ***Can you try to explain that?*** *So, if we* ***write down what happened****, yes?... ok, so, the ice cube on the surface that feels cold melted much quicker, that's what happened. That's the observation, yeah? 'The ice cube on the surface that feels colder melts quicker'. Ok?* ***Why? What are the key words here? What are the key words that we need to put into our explanation?*** (E#4-Ch)

Table 4.6.1.4.b) Types of activities present in Christian's episodes on explanation

TYPE OF ACTIVITY	EXAMPLES
Student experiment (in pairs)	Ch.- Guys, there is an ice cube, ok?... 1,2,3,4,5,6,7… so, normally, we do 4 pairs, but **today it's 3 pairs and one person works on their own.** So, we've got an ice cube and marble, which is really dense (…). You've got to heat… the water is gonna be for… **all you have to do is this, ok?** So, you pour some water in, all right? S1.– To heat the marble. Ch.– Well, the marble is at the bottom, right? So, what you're gonna do, after pouring the water, you're gonna tilt it, and heat it near the top, ok? Heat it near the top and see what happens. (…) S2.– Well, it eventually melted. Ch.– Yes, it eventually melted. Claude was heating probably too long, the first group, they were heating for, at least, three minutes, maybe more, maybe five minutes, and after five minutes, eventually the ice cube melted. So, the heat did travel down the water, but only very slowly, ok? Now, **why is that? So: solids for about five minutes (maybe exaggerating a little bit) ... Why? Why is this? Does anybody get any suggestion?** (E#5-Ch)
Book-based activity (with pair and whole class discussion)	*Ch. – **Open your books at the lesson when you were doing the neutralisation**, with that long thing burette, remember? Excellent. Ok.* *(…)* *We know that the colour went from being purple to blue and eventually green, maybe even yellow. But, to get to neutral, what do you think was being made? Ten seconds, again, **talk to your partner**. What do you think was being made? 10 seconds! 5 seconds, ok, hands up!* *S1.– Water?* *Ch.– Hands up if you agree with that. If you think it's water. We have 4 people who agree, ok. Now, hands up if you disagree. Ok, you're very brave. Now**, why do you disagree?** We put an indicator. The indicator, as you know, is something that changes its colour whether it's in an acid or in an alkali. Yeah? Remember we did our own cabbage indicator? And it changes colour depending on how acid or how alkali, or if it's neutral, changes colour. (…). There's no way of knowing when it's neutral. That's why you use the indicator.* ***So, why do you think we made water? What makes you think that's a good answer?*** (E#9-Ch)
Student experiment (individually)	Ch.– You're gonna put your ink in this line, ok? This line. (…). Ok, now, Cristine, when you put the paper in, what can you tell us about the water and the paper? (…) Are they soluble or are they insoluble? S1.– Insoluble. Ch.– So, they don't dissolve. S1.– Yes. Ch.– But, if they are insoluble, they will stay where they are. S1.– They're soluble. Ch.– They're soluble because they are moving with the water, right? The pencil stays where it is, but the inks move. So, they are soluble, fair enough? Make sense? Ok. Now, can you see that, in some of these inks there's more that one… compound? There's more than one substance in there? Can you see that? Ss.– Yes. Ch.– And they get separate! Now, **why are they getting separated? Why would they possibly get separated?** (E#14-Ch)

The analysis of Christian's specific discourse moves may help us comprehend how he engages students in reasoning to build explanations. As Table 4.6.1.4.c shows, Christian's Initiating moves are of two types: introduction moves and eliciting moves (Harris *et al.,* 2012). Within the first category, we find those situations when Christian presents the phenomenon that will be asked to be explained, either through an experiment/demonstration (E#14-Ch and E#15-Ch), either by referring to something seen in a previous lesson (E#9-Ch). Sometimes, Christian directly poses the explanation construction as a problem that must be solved (E#8-Ch). Another way to initiate an explanatory episode is by elicitation of students' ideas and/or questions. To achieve this, Christian raises specific questions about aspects related to the phenomenon they will try to explain. Of particular interest is the case in which the episode begins with Christian asking students to predict what will happen in a video, and then asking them to explain what actually happens (E#3-Ch)[38].

Christian's initiating moves open a dialogue which is constrained by his Continuing moves. He implements different strategies to guide students in the production of the explanation, encouraging them to elaborate and expand their own thinking or that of their peers. The most used Continuing move is question-posing. Through questioning (which includes factual, convergent, guided, chained, and yes/no questions), Christian tries to elicit students' grasp of content knowledge (E#9-Ch). Christian also asks questions aimed at inviting thinking and reasoning. This included making predictions (E#11-Ch), and asking for the reasons behind the given answers (E#9-Ch). In addition to providing prompts to stimulate and maintain the development of the explanation (E#3-Ch), Christian poses questions to build upon some students' contribution (E#2-Ch) or to contribute with different ideas (E#8-Ch).

When Christian wants to introduce new perspectives to expand the explanation-building process, he uses different Extending moves. On some occasions, these moves allow him to lead or redirect the explanation into a specific direction, such as when he makes a speech full of rhetorical questions, when he selects examples of everyday life (E#4-Ch), or when he rephrases a student's contribution (E#6-Ch). Other times, he opens the discussion to new perspectives, focusing on those that conflict with the position or idea a student is defending (E#15-Ch).

For Christian, it is essential that students maintain a positive relationship with their learning. Therefore, his evaluative comments are always encouraging and supportive. Throughout the different episodes on explanation construction, Christian constantly thanks, encourages, values, challenges, and praises students to keep them motivated during this hard task.

[38] See §4.4.2.3 for an introduction on POE sequences

Table 4.6.1.4.c) Discourse moves present in Christian's episodes on explanation.

CHRISTIAN'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Initiating moves	Direct instruction (new problem)	*Ch.– Now, the question is: why are they not all the same? Yes? So, what we've got**? My walk took the same amount of time, but they are all different**. I mean, the only ones that are the same are these two, but nothing else is the same, isn't it? **You have a whole minute to try to discuss why they are different**.* (E#8; Y9.O1.C-Ch)
	Student's question	*S1.– **Why is it one minus $(^{-})$?*** *S2.– Because it's a non-metal.* *Ch.– Because it's a non-metal, and non-metals form negative ions. How many electrons are there in chlorine outer shell? Normally. Normally, how many. Which group is it in?* *S1.– Seven.* *Ch.– Seven electrons. So, when it gets one, it fills the outer shell. (E#12; Y10.O3.C-Ch)*
	Recalling/ Factual question	Ch.– So, Carlos, **how is the heat reaching us from the Sun?** because it's a long way away and it get here. S1.– Ahm… (E#6; Y10.O1.P-Ch)
	Refers back to a prior session	*Ch. – Open your books at the lesson when you were doing the neutralisation, **with that long thing burette, remember?** Excellent. Ok. Now, the first question for you this morning is **what were the names of the two chemicals that we were mixing?** So, we got sodium hydroxide at the bottom, and that was one chemical, and then, **there was a different chemical in the burette that you filled up. Can you remember the name?** work in pairs in ten seconds, just to remember the names of these chemicals.* (E#9; Y7.O2.S-Ch)
	Demonstration (introduces the phenomenon)	*Ch.– So, if **you got this bulb, and inside the bulb there's this very large amount of liquid**, ok? I'm just gonna colour it in red here. Most of these thermometers have alcohol in them, because alcohol, as phenol, is pure and clear transparent, which is not good, is it? So, they put a little bit of dye to make sure you can see it. In those one, it's kind of green. That one you've got is mercury. **Now, this liquid is expanding as your hands are around it. But the bulb is also expanding, because solids also expand. What's the difference between the way the glass is expanding…?*** *S1.– It's slower.* *Ch.– So, it's expanding less, isn't it?* (E#15; Y10.O2.P-Ch)
	Experiment (introduces the phenomenon)	Ch.– **You're gonna put your ink in this line, ok? This line. (…). Ok, now, Cristine, when you put the paper in, what can you tell us about the water and the paper? What does the water do when it hits the paper? Does it stay exactly where it was?** S1.– Ahm…, no; it goes higher. Ch.– It goes up. (E#14; Y8.O2.S-Ch)
	Makes a statement + recalling question	*Ch.– **In here it's just neutral. Can you see that? How do we now get dry pure crystals of sodium chloride?** From this.* *S1.– Filter. – we don't need to filter anything! (E#13; Y10.O3.C-Ch)*
	Asks for a prediction	*Ch. – **Before you do, let's just think about it, let's make predictions**. So, we know that nothing really happened with water. With vinegar, which is a weak acid, you get quite a lot fizzing, what shows that a gas is made. **What's your prediction with HCl?*** *S1.– It will dissolve.* *Ch.– Ok, will it dissolve? Maybe. (E#11; Y7.O2.S-Ch)*

Table 4.6.1.4.c) Discourse moves present in Christian's episodes on explanation.

CHRISTIAN'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Continuing moves	Reasoning question	*Ch.– So, let's just say we've got a liquid in there, ok? And your hands go on at 37 degrees;* ***what would happen here? What would happen here?*** *Discuss to the person close to you, 30 seconds. Ok, guys, what did you get? (…) Claire**, what would be different between these two?** (*(E#15; Y10.O1.P-Ch)
	Asks for justification	*Ch.– Now, Chase,* ***why do you think that this one is gonna melt quicker?*** *S3.- Because it doesn't feel cold, and it should in a way says it's warmer, it's because [inaudible] some heat on it. And… that's all, I don't know.* *Ch.– Ok. Thank you very much.* (E#4; Y10.O1.P-Ch)
	Convergent Questioning	*Ch.– Air. And that's a mixture, isn't it? What's in the mixture, Caroline?* ***What gases are in the air?*** *S2.– Ahm, oxygen, …, ahm, can't remember.* *Ch.– No problem.* ***What is in there, apart from oxygen?*** *S3.– Nitrogen?* *Ch.– Nitrogen. More than 80. And a little bit of…* *S3.– Argon.* *Ch.– Argon! And then, a little tinnier bit of…* *S4.– Carbon dioxide.* *Ch.– Ok* (E#7; Y10.O2.P-Ch)
	Closed Questioning	*Ch.–* ***Are they soluble in water?*** *S2.– Yes.* *Ch.–* ***Are they the same solubility?*** *Ss.– No.* *Ch.– Which is more soluble?* *S2.– The blue.* *Ch.– Yes! (E#14; Y8.O2.S-Ch)*
	Provides some prompts	*Ch.– Do you know that some things dissolve in water? Other things don't. how do we call something that dissolves in water?* *S1.– Soluble.* *Ch.–* ***And if it doesn't dissolve is…*** *S1.– Insoluble.* (E#14; Y8.O2.S-Ch)

Table 4.6.1.4.c) Discourse moves present in Christian's episodes on explanation.

CHRISTIAN'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Continuing moves	Poses guided questions	*Ch.– We think is gonna make some bubbles. Would it make more bubbles, or would it make less bubbles than vinegar?* *S3.– I think it's gonna make more.* *Ch.– And why would it make more?* *S3.– Because it's a stronger acid.* *Ch.– It's a stronger acid, ok. Now, you are right on your prediction.* (E#11; Y7.O2.S-Ch)
	Poses chained questions	*Ch.– Excellent. So, free electrons, what kind of materials may have electrons that are not tightly held?* *S1.– Metals.* *Ch.– Excellent, ok? And they are… aim to do what, these free electrons? (…) Just a little demonstration of this. Ahm… if I was holding a metal stick, yeah?, and one end of the metal stick is put into a very hot flame here, well, what would happen to my hand?* *S2.– It will get burnt.* *Ch.– I will get burn, all right? Ok, so, what about this? This piece of wood, ok? If I hold it in there, what's gonna happen to my hand?* *S2.– Nothing.* *Ch.– Nothing at all. Why not?* *S3.– The conduction… it's an insulator.* *Ch.– What's an insulator? The wood is an insulator.* (E#2; Y10.O1.P-Ch)
	Asks for keywords to build an explanation	*Ch.– That's the observation, yeah? 'The ice cube on the surface that feels colder melts quicker'. Ok? Why**? What are the key words here? What are the key words that we need to put into our explanation?*** *S1.– Energy.* *Ch.– Thermal energy, that's good. What else?* *S1.– Insulator.* *Ch.– Insulator.* *S2.– Conductor. . – Ok.* *S3. – I'm not sure how to write the explanation.* *Ch.–* ***We're gonna write it, but before we do, we're gonna put down some key words that we need to put in there****.*
	Asks for predictions	*Ch.– This one feels cold, this one doesn't feel cold. It's the only difference, really. Ok, well, this one was heavier, this one over here is lighter.* ***So, what do you reckon, guys?*** (E#4; Y10.O1.P-Ch)
	Rephrases	*Ch.– What's the difference between the way the glass is expanding…?* *S1.–* ***It's slower.*** *Ch.–* ***So, it's expanding less, isn't it?*** (E#15; Y10.O2.P-Ch)

Table 4.6.1.4.c) Discourse moves present in Christian's episodes on explanation.

CHRISTIAN'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Continuing moves	Asks for more contributions	*Ch.–* ***Anybody has something to add?*** *S1.– So, the energy is transferred along…* *Ch.– Yeah. So, it has to do with the vibration and the kinetic energy of the particles in the solid.* (E#2; Y10.O1.P-Ch)
	Direct instruction	*Ch.–* ***Can you try to explain that? So, if we write down what happened, yes?...*** *Ok, so, the ice cube on the surface that feels cold melted much quicker, that's what happened. That's the observation, yeah? 'The ice cube on the surface that feels colder melts quicker'. Ok? Why?* (E#4; Y10.O1.P-Ch)
	Asks for a different participant	*Ch.– In solids, heat travels by conduction. But, how about in fluids? So, in liquids and in gases. How does the heat travel?* *[Silence].* *Ch.–* ***Pass it on? do you know? No? Ok, anyone else? Camille?*** *S2.– Convection currents.* *Ch.– Convection! Not conduction, but convection*
	Provokes cognitive conflict	*Ch.– Pencil is made of graphite, isn't it? Not lead, it's graphite.* ***And it's insoluble. So, will it move with the water?*** *S1.–* ***No.*** *Ch.–* ***No! because it doesn't dissolve. No, these inks that are moving, what do you know about them? Are they soluble or are they insoluble?*** *S1.–* ***Insoluble.*** *Ch.–* ***So, they don't dissolve.*** *S1.–* ***Yes.*** *Ch.–* ***But, if they are insoluble, they will stay where they are.*** *S1.–* ***…They're soluble.*** *Ch.–* ***They're soluble because they are moving with the water, right?*** *The pencil stays where it is, but the inks move. So, they are soluble, fair enough? .* (E#14; Y8.O2.S-Ch)
	Invites elaboration	*Ch.–* ***Anybody wants to go a bit deeper?*** *S1.– Oh! Is that free electrons that…?* *Ch.– Excellent.*
	Invites reasoning	*S1.– Mmm… conduction.* *Ch.– Conduction. Excellent, very good, well done.* ***Can anyone describe how is the conduction process happening?*** *Anyone be brave and have a go! Claude.* *S2.– Mmm, vibration gives heat, ahm…, gives more energy to the particles, so they vibrate more, and the vibration causes […].* *Ch.– Very good effort at explaining.* (E#2; Y10.O1.P-Ch)

Table 4.6.1.4.c) Discourse moves present in Christian's episodes on explanation.

CHRISTIAN'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Extending moves	Rhetorical questioning	*Ch.– So, what is it that glass and wood don't have in their structure that metals have?* *S1.– Free electrons.* *Ch.– Free electrons,* ***ok?*** *So, all the electrons are used in… bonding****, yes?*** *They are not able to sort of, move freely****, ok?*** *At a certain point the flame will reach my fingers,* ***yes?*** *Clearly it is very hot on one end, but it's not hot, this end. I mean, trust me. You hold that in…* ***you did in a bonfire? You can toast a marshmallow****… this end, could be, you know, 500 degrees, in the flame. But this end, not. So, the heat is not travelling, or at least, it is not travelling very well,* ***ok?*** *All right.* (E#2; Y10.O1.P)
	Checks for disagreement	*Ch.– What do you think was being made? 10 seconds! 5 seconds, ok, hands up!* *S1.– Water?* *Ch.– Hands up if you agree with that. If you think it's water. We have 4 people who agree, ok. Now,* ***hands up if you disagree. Ok, you're very brave. Now, why do you disagree****?* (E#9; Y7.O2.S-Ch)
	Rephrases and adds information	*Ch.– There's something else with temperature that has a much bigger effect than just increasing the number of collisions.* *S1.– I'm not sure, but, because there's more temperature, they have more energy to pass… so, because to make collisions successful for the reaction there has to be a certain amount of energy…* *Ch.–* ***Ok, let's talk about this again, right?*** *So, if they miss each other, there is no chance of reaction. If they hit each other with not enough energy, they don't react. But if they hit with enough energy, they will react. (E#10; Y10.O3.C-Ch)*
	Provides examples	 *Ch.– Ok, all right. Yeah? So,* ***you've got the angels here****, and, at the moment, they are completely still, yes?, not a lot of movement. But* ***if we put a heat source under them, the air is being heated above the flame, which means that their particles are moving faster, which means they need to take more space, which means that area of air is less dense****. So, less areas move up, yeah?* (E#3; Y10.O1.P-Ch)
Referring moves: Makes explicit links to	Prior activities /situations	*Ch.– 'How does heat travel in solids',* ***we talked about that****. Now, how does heat travel in fluids?* (E#3; Y10.O1.O-Ch)
	Prior contributions	*Ch.– Ok,* ***Chris has told us why, I hope you all listened. But, please, Chris, tell us one more time.*** *S1.– Yes. Conduction doesn't work very well in liquids. – perfect.* (E#5; Y10.O1.P-Ch)
Replying moves	Responds to explicit comments	*S3.- I'm not sure how to write the explanation.* *Ch.–* ***We're gonna write it, but before we do, we're gonna put down some key words that we need to put in there****.* (E#4. Y10.O1.P-Ch)
	Responds to explicit questions	*S1.- Why not 'YY'?* *Ch.–* ***You cannot have such a thing, because all eggs are X's, right?*** *Sperms are 50% Y's and 50% X's.* (E#1; Y8.O1.S-Ch)

Table 4.6.1.4.c) Discourse moves present in Christian's episodes on explanation.

CHRISTIAN'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Replying moves	Admits not to know an answer	*S1. – Why is ammonia so bad smelly?* *Ch.– **I don't know that answer**. Obviously, it is interacting, isn't it? With your…, your sensory glands in your nose, in that area**… I have no idea, no idea. The whole science of smell is a mystery to me, to be honest with you***. (E#16; Y10.O3.C-Ch)
Commenting/Reinforcing moves	Makes a motivational statement	*Ch.– What makes you think that's a good answer?* *S1.– Water is one of the only neutral substances.* *Ch.– **Great answer! Very good, that's excellent**.* *S2.– Because if you have water you need hydrogen, which is H, and Hydroxide, which is HO, which is what makes something acid and what make something alkali… so, if you add and acid to an alkali to make it neutral, then, the H and the HO combine in H2O.* *Ch.– **That is a great answer. That's a fantastic answer**. He knows that water is H2O, he knows that acids got H, he knows Hydroxide is OH. If you put H and OH together, you get H2O. that's a great answer. **Very, very good**.* (E#9; Y9.O1.C-Ch)
	Explicitly shows agreement	*Ch.– How many people think is gonna make some bubbles? Ok, everyone, right? We think is gonna make some bubbles. Would it make more bubbles, or would it make less bubbles than vinegar?* *S3.– I think it's gonna make more.* *Ch.– And why would it make more?* *S3.– Because it's a stronger acid.* *Ch.– **It's a stronger acid, ok. Now, you are right on your prediction**.* (E#11; Y7.O2.S-Ch)
	Makes a challenging remark	*Can anyone describe how is the conduction process happening? **Anyone be brave and have a go!** Claude. (E#2; Y10.O1.P-Ch)*
Concluding moves	Introduces a subsequent activity	Ch.– Ok. Well, **we've got a short video to watch, and you are going to make predictions in the middle of this video. And then, they'll show us an experiment, and you can see if you were wrong or right**. Ok, it's a video about conduction, well, not really specifically conduction, it's more to do with insulation. (E#3. Y10.O1.P-Ch)
	Summarises (by naming a concept/idea)	*Ch.– So, the heat is not travelling, or at least, it is not travelling very well, ok? All right**. That was a bit of revision about conduction**.* (E#2; Y10.O1.P-Ch)
	Rephrases a student's contribution and makes a positive statement	*Ch.– That is a great answer. That's a fantastic answer. **He knows that water is H2O, he knows that acids got H, he knows Hydroxide is OH. If you put H and OH together, you get H2O. That's a great answer. Very, very good***. (E#9; Y9.O1.C-Ch)

Table 4.6.1.4.c) Discourse moves present in Christian's episodes on explanation.

CHRISTIAN'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Concluding moves	Checks understanding and summarises	*Ch.– So, what we're talking about is separating thing that are less or more soluble.* ***Fair enough?*** *S1.– Yes.* *Ch.–* ***So, that's why it's a separating technique. You are separating here certain parts of the ink that are more soluble than others. Make sense? You can use it to identify things****.* (E#14; Y8.O2.S-Ch)
	Summarises (and adds some information)	*S1.– You don't count middle seconds in your head. And with the timer you can, so you have more accurate results.* *Ch.– Yes. So, these ones are not the same level of accuracy as the timer on the mobile phone or that one.* ***They are more accurate. They can give you 1/100 of a second****.* (E#8; Y9.O1.C-Ch)
	Provides correct answer	*Ch.– Not pretty sure about it, ok.* ***This is what it happens in reality****. The diameter of this one is much bigger. Just imagine it is the same size. So, overall, the expansion is, let's say, 2mm3, right? 2mm3 in a thin tube is a big difference, whereas in the big one, is not. So, here, you will have to have 20, 21, 22, 23… that will be the difference between 20 and 37, whereas here, you could have that as the difference between 20 and 37. And you can have a lot more spaces and, as L. said, it would be more accurate, wouldn't it? Makes sense?* (E#15; Y10.O2.P-Ch)
	Does not give a final answer	*S1. – Why is ammonia so bad smelly?* *Ch.– I don't know that answer. Obviously, it is interacting, isn't it? With your…, your sensory glands in your nose, in that area****… I have no idea, no idea. The whole science of smell is a mystery to me, to be honest with you****.* (E#16; Y10.O3.C-Ch)
	Provides time for explanation improvement	Ch.– Now, having listened to someone else's, is there any way you think you could improve yours? Something you could add to yours? You've got one minute to add something that, after listened someone else's explanation, you say 'Oh, I like that!', or 'I wanna use that word'. **You've got one minute to improve your explanations**. (E#4; Y10.O1.P-Ch)
	Refers to reality	*Ch.– Gases are even worse at conducting heat. So, it's all about transferring these vibrations from one particle to the next, and in gases, they spread so far apart that it's even slower than in liquids. In gases, conduction still happens, but very slow.* ***If you have double glazing at home, rather than air between the two panels, it would be a vacuum, yeah? So, if you want to stop the conduction, you've gotta remove all the gas in there, you've gotta remove all the particles, ok?*** (E#5; Y10.O1.P-Ch)
	Repeats and makes a confirming comment	*Ch.– Why are we gently heating it?* *S1.– To evaporate the water.* *Ch.–* ***To evaporate the water, exactly!*** *That's what we're gonna do, right? So, you gently heat it, and then, you leave it on one side*. (E#12; Y10.O3.C-Ch)

Concluding moves adopted by Christian are usually aimed at recapitulating and closing off the explanation episodes. Then, he often summarises what has been said (rephrasing or adding some information) or provides a conclusive explanation. On other occasions, Christian does not give a conclusive answer; either because he does not know it (E#16-Ch), or because he wants the students to produce their own explanations (E#7-Ch). Finally, we find episodes in which Christian connects the activity they are doing with the next activity (E#3-Ch, E#10-Ch).

The communicative moves performed by Christian can be grouped into sequences or patterns of interactions that give us an idea of how he works to develop the scientific explanation and to make the process available to all the students (Table 4.6.1.4.d). In Christian's way of interacting, we cannot establish a clearly dominant pattern. That is, although in most of the episodes there is some kind of triadic-like exchange, within these, we find numerous and complex variations. The key to understanding this variation is in the third move, that is, in the Evaluation phase. So that students express their views, Christian does not usually make categorical evaluations of their answers but prefers to maintain a neutral tone and/or to prompt further elaboration; this gives rise to chains of interaction which take a multiplicity of forms.

In Christian's interventions, we can appreciate what we can call IRE(F)P sequences (Scott *et al.*, 2006). In them, Christian Initiates an exchange with a question or a direct instruction (I), to which a student provides a Response (R). Some responses involve only single words, while others involve higher-level elaboration. Sometimes, several students respond before Christian has time to comment anything (e.g., E#15-Ch). To the answers provided by the student(s), Christian makes an Evaluation (E). This may be a very brief remark –"*excellent*", "*Ok*, *all right*. *Yeah*?", "*perfect answer*, *yeah*?"– or a quite long comment (E#8-Ch). In some cases, the evaluative element is absent (NE). On many occasions, instead of adding something to the answer and asking the student to follow up in her reasoning to deepen her response (F), Christian addresses another student or the group with a prompt (P). Christian's prompt move is, then, followed by an additional response. Most chains of interaction are closed by a final evaluation from Christian (E#2-Ch), while others remain open without any final evaluation (E#4-Ch). These patterns result in explanatory dialogues in which more than one student are involved, reinforcing the sense of a learning community that negotiates and co-constructs content. In Table 4.6.1.4.e, I present the chains of triadic-like sequence of interaction I found in each of Christian's episodes. It can be appreciated both the variety and the complexity of these sequences.

Table 4.6.1.4.d) Christian's patterns of interaction.

CHRISTIAN'S PATTERNS OF INTERACTION	EXAMPLES
Teacher's question – teacher's answer	*Ch.– The only thing you are not sure about is whether the area of the fluid becomes more dense or less dense when heated. What do you know about the particles in the area that is being heated?* *S1.– They move faster.* *Ch.– They are moving faster, so they are going to take more space. If the same amount of stuff takes more space, is it less dense, or is it more dense?* *S1.– I don't know.* *Ch.–* ***Ok, what's the formula for density?*** *[silence]* *Ch.–* ***Density equals mass divided by volume, ok.*** (E#3-Ch)
Student's question – Teacher's answer	*S1.- Why not 'YY'?* *Ch.–* ***You cannot have such a thing, because all eggs are X's, right? Sperms are 50% Y's and 50% X's***. (E#1-Ch)
Student's intervention without being interrogated	*Ch.– So, here we go: heat…ok, so, the explanation: even though… well, not the explanation, the description: 'even though the water at the top was boiling, the ice cube stays solid'...* *S2.–* ***Well, it eventually melted.*** ***Ch.– Yes, it eventually melted.*** *Claude was heating probably too long, the first group, they were heating for, at least, three minutes, maybe more, maybe five minutes, and after five minutes, eventually the ice cube melted.* (E#5-Ch)
Out loud reading	*"We're gonna read a model answer, which is on page 111. (…). Here we go, page 111.* ***We're gonna read out one word at a time****, focus, one word. We're gonna star with Claus.* (E#7-Ch)
Alternation with interruptions	Ch.– Your hand is in contact with it, isn't it? It's actually in contact. **What's the kind of heat… S1.– Conduction.** Ch.– Remember that radiation is when it's travelling through… so, when it's in contact, it's probably more a matter of conduction. (E#7-Ch)

Table 4.6.1.4.d) Christian's patterns of interaction.

CHRISTIAN'S PATTERNS OF INTERACTION	EXAMPLES
IRE(F)P complex sequences	*Ch.–* ***So, how does heat travel in solids? [E-FN: dice].*** ***S1.– Mmm… conduction.*** ***Ch.– Conduction. Excellent, very good, well done. Can anyone describe how is the conduction process happening?*** *Anyone be brave and have a go! Claude.* *S2.–* ***Mmm, vibration gives heat, ahm…, gives more energy to the particles, so they vibrate more, and the vibration causes […].*** ***Ch.– Very good effort at explaining. Very good, yeah. Anybody has something to add?*** *S1.– So, the energy is transferred along…* *Ch.– Yeah. So, it has to do with the vibration and the kinetic energy of the particles in the solid.* (E#2-Ch)
Student-student interaction	Ch.– Can you remember the name? **Work in pairs in ten seconds**, just to remember the names of these chemicals. Five seconds. 3, 2, 1. (E#8-Ch)
Group sharing	Ch.– Who knows? **Hands up!** (E#8-Ch)
Student interventions sequences	Ch.– Now, why is it that we have a very, very thing glass tube inside? **S1– To make it more accurate.** **S2.– So, the heat goes directly to the…** Ch.– So, how did it different if we had that, and that, and the bulb here was like that? S3.– It would take longer. Ch.– What would it take longer? S3.– The liquid to raise. (E#15-Ch)
Hesitations and pauses	*Ch.– Celia, how does heat travel in fluids?* *S1.–* ***Mmm…*** *Ch.– In solids, heat travels by conduction. But, how about in fluids? So, in liquids and in gases. How does the heat travel?* *S1.–* ***[Silence].*** *Ch.–* ***Pass it on? do you know? No? Ok, anyone else?*** *Camille?* *S2.– Convection currents.* *Ch.– Convection! Not conduction, but convection.* (E#3-Ch)

Table 4.6.1.4.e) Chains of triadic patterns of interaction in Christian's episodes

SI: Student intervention; I: Initiating move; R: Response; E: Evaluation; NE: No evaluation; P: Prompt; F: Follow-up; si: student number; H: hesitation; C: checking understanding; A: asking for agreement

EPISODE	SEQUENCE
#1	**SI_{S1}-R**
#2	**I- R_{S1}- E/P- R_{S2}- E/P- R_{S3}- E/P- R_{S4}- E/P- R_{S5}- E/P- R_{S5}- E/P- R_{S5}- F- R_{S6}-F/P- R_{S7}- E/P- R_{S7}- E/P- R_{S7}- E/P- R_{S7}- E**
#3	**I- H_{S1}- P- H_{S1}- P- R_{S2}- E/P- R_{S3}- F/P- R_{S3}- F/P- H_{S3}- P- H_{S3}- P- R_{S3}- E**
#4	**I- R_{S1}- C- R_{S1}- NE/P- R_{S2}- C- R_{S2}- NE/P- R_{S3}- NE/P- R_{S4}- F- R_{S4}-NE- I- R_{S1}- E/P- R_{S2}- NE- R_{S3}- NE**
#5	**I- R_{S1}- F- R_{S1}- E/P- R_{S2}- E- SI_{S3}- E/I- R_{S3}- E/P- SI_{S4}- E- SI_{S5}- P- R_{S6}-E/P- R_{S7}- F- R_{S7}- E/P- R_{S8}- E**
#6	**I- R_{S1}- E/P- R_{S2}- E/P- R_{S3}- E**
#7	**I- R_{S1}- E/P- R_{S2}- E/P- R_{S3}- E/P- R_{S3}- E/P- R_{S4}- I- R_{S5}- A- R_{SS}- E**
#8	**I- R_{S1}- E/P- R_{S2}- F…- SI_{S2}- E**
#9	**I- R_{S1}- E/P- R_{S2}- F- R_{S2}- E/P- R_{S2}- E/P- I- R_{S3}- A/P- R_{S4}- E- SI_{S5}- E**
#10	**I- R_{S1}- E/A/P- R_{S2}- E**
#11	**I- R_{S1}- NE/P- R_{S2}- A/P- R_{S3}- F- R_{S3}- E**
#12	**SI_{S1}- R_{S2}- E**
#13	**I- R_{S1}- E/P- R_{S2}- E**
#14	**I- R_{S1}- F- R_{S1}- F- R_{S1}- E/I- R_{S2}- E/P- R_{S3}- E/P- R_{S3}- E/P- R_{S4}- F- R_{S4}- F- R_{S4}-E**
#15	**I- R_{S1}- F- R_{S1}- E- R_{SS}- I- R_{S1}- R_{S2}- P- R_{S3}- C- R_{S3}- F- R_{S4}- A- E**
#16	**SI_{S1}- R**

In addition to complex triadic sequences, in Christian's case, we find many other patterns of interaction (Table 4.6.1.4.d, previous pages). The most repeated is student-student interaction. It is very common that in the middle of an episode of explanation building, Christian asks his students to discuss something in pairs. This ranges from just a few seconds to find a word (E#9-Ch), to episodes of several minutes in which students must answer a cognitively more demanding question (E#2-Ch). When students are working as a dyad, Christian does not interfere in their discussions. Once the discussions are finished, Christian invites students to share their ideas, questions, and outcomes. He structures these opportunities as whole-class reporting sessions. Christian never addresses a student directly but asks for volunteers (E#8-Ch), or rolls a dice to generate a random number (what he calls 'the dice of destiny' (E#10-Ch)).

There are episodes in which the usual role questioner-questionee is altered. And episodes in which a student intervenes with a comment or question without having been directly addressed, which Christian incorporates into his discourse. Another way to intervene in the classroom is by reading aloud. In episode #10, Christian asks the students to read a model answer[39]. During the reading, Christian usually makes some pronunciation corrections, but does not comment on the content until the end. Finally, we find less structured episodes, in which a student interrupts Christian before he finishes a question/phrase or students who stop and/or hesitate when trying to answer, to whom Christian must help with cues so they can continue talking.

4.6.1.5. Christian's Knowledge of Assessment (KAs)

Christian's lessons are carefully designed according to his educational goals, his way of conceptualising science and his orientation towards teaching and learning. We can characterise Christian's classes as sets of scientific practices that revolve around natural phenomena. For Christian, assessment is a fundamental dimension of the teaching-learning process. In his sessions, diverse assessment methods are successfully intertwined with his teaching, which indicates a deep knowledge of assessment (KAs).

As mentioned in Section 4.6.1.1, Christian would like students to stop worrying about exams and focus on other aspects of learning, to create positive relationships with them. This is one of the reasons why Christian introduces a wide variety of informal assessment tools that are stimulating and attractive (and even fun) for students. As for the construction of explanations, Christian strives to have diversity within the same activity. Thus, we find episodes which includes pair-discussions, whole-class dialogues, hands-on activities, video watching, reading aloud, demonstrations and writing, all accompanied by Christian's questioning and comments. Christian's purpose of informal assessment is twofold: on the one hand, to keep the students engaged in the task. And, on the other, to monitor their performance, to accommodate his teaching strategies accordingly. The latter requires not only to be very clear about the learning objectives, but also to know the students in-depth. That Christian had developed a specific sequence of instructions for teaching how to elaborate scientific explanations (§4.6.1.4) indicates he has some idea about what he wants the students to learn.

One of the phases of the aforementioned instructional sequence comprises the individual writing of the co-constructed explanation. That is, as a result of the performance process, students compose an individual and evaluable product. It would allow Christian to assess students' explanations not only from an informal and formative perspective but also, summative, and formal. That students know that the explanations they write will be included in their workbook for subsequent assessment might influence the value they give to such epistemic

[39] This is something present in many of his lessons. In an informal conversation, Christian told me that he makes them read aloud because a high percentage of students do not have English as their first language (EAL), and any activity that helps them improve their ability to learn English is welcome in the classroom.

practice (§4.6.1.3). I think it would be enlightening to study this influence in detail, but it is beyond the scope of this thesis.

Besides the product, Christian also values students' efforts to produce explanations. This is something he externalises when his students are involved in the building process (E#2-Ch). That students perceive this positive and explicit feedback could encourage them to give some value to the formulation of explanations as practice.

Christian seems genuinely concerned about the quality of the explanations that students build in the classroom, which might suggest that, although not necessarily formally structured, he has some mental model of what a high-quality explanation consists. The last phase of the specific instructional sequence he uses is very revealing in this regard (Figure 5.4.1.a). Christian boosts students to produce an improved version of their explanations after listening to one or more classmates –"*Now, having listened to someone else's, is there any way you think you could improve yours? Something you could add to yours? (…).* ***You've got one minute to improve your explanations***" (E#4-Ch). This same strategy was observed in a cross-national comparative study between the United States and Germany (Forbes *et al.,* 2014). Forbes and his team reported that only in the American case was it possible to find some examples in which the teacher did provide opportunities for students to assess the quality of their explanations through comparison with their peers' explanations for the same phenomena.

The main difficulty I encountered for my analysis is that Christian never specified to students what he considers when assessing their explanations. Is it merely the number of keywords that they include in their explanation? Is it the logic of the narrative? The correctness of the content? Does he assess how students use language? How they reason? Aware of how powerful it may be to make explicit for students the epistemic goals of science practices (Dunbar 1993), I asked Christian what he expected students to achieve when building an explanation. He gave me some clues, although without too much specification:

> *"The thing that I value the most is their effort, their work. Eh ..., also, ..., I usually appreciate good ideas. Even if they are a little, you know, crazy; but I like good ideas. I like them to think for themselves, not to solve a problem in the way they think I would do it. I value this kind of things very positively."* (I-Ch)

4.6.1.6. Christian's PCK of Scientific Explanation. Summary and discussion

Christian is a highly experienced teacher whose way of understanding science and science learning steers him to create a learning environment in which practice-based learning is emphasised. In Section 2.3, I narrated how in the last decades, both researchers and educators have recommended a shift away from teaching science as a body of established knowledge – science-as-knowledge– towards experiencing science as a method of generating, validating, and applying such knowledge –science-as-practice– (Pickering, 1993; Soler *et al.*, 2014). From this perspective, to be proficient in science, students should not only acquire a set of science concepts, methods, and skills but to become legitimate participants in different epistemic practices and discourses (Duschl *et al.,* 2007). Reframing students' learning expectations around engagement in discursive and epistemic practices has important consequences for the classroom, in terms of (i) the students and teacher's role, (ii) the social organisation, and (ii) the kind of discourse used.

i) *Role changing*. When students' engagement goes beyond solving drill activities whose purpose is to confirm canonical knowledge, and beyond being merely exposed to definitions of what a scientific practice is (Stroupe, 2015), they need to take on a new role as epistemic agents. Epistemic agents have ideas, interests, and intentions, and should, then, share the responsibility of constructing knowledge. I witnessed many situations in which Christian acted as a guide for the students while engaging in an epistemic practice. Christian strived to provide support and scaffolding to students, whose ideas and beliefs were elicited, commented, and considered for the development of the activity. In the episodes of explanations production, the students answered Christian's questions but also posed their own questions; they provided keywords to explain the phenomenon; they discussed with each other; they sometimes disagreed; they justified their answers and reasons; and they developed their own explanatory accounts. In short, they acted as individual epistemic agents within a community. In this sense, then, the roles played by Christian and his students fit in with a practice-based approach to science. Something very characteristic of the practices in which Christian's students were involved is that they could experience phenomena directly. Given that the selected phenomena were always related to some aspect of the curriculum and content, we can say that Christian advocated for what Svinicki and McKeachie (2011) call 'experiential learning'.

ii) *Social organisation*. One of the aspects scholars agree about is that discipline-based epistemic practices are always performed by communities within particular contexts with their particular cultural norms (Osborne *et al.*, 2003; Kelly & Licona, 2018, Chang, 2011), which are supported by a network of social and institutional frameworks (Moura & Guerra, 2016). Duschl (2008) insisted on the need to find a harmonious balance between the conceptual dimension, the epistemic dimension and the social dimension that each practice possesses. Regarding the social dimension, what should be sought in the classroom is for students to participate in the consensual elaboration of the norms that define each practice, their implementation, and the success criteria, in addition to getting involved in the practice as a community. For all this to be satisfied, classrooms should become real communities of practice where students work towards shared goals (Kaartinen & Kumpulainen, 2004). This requires teachers to create and sustain learning environments in which dialogue is promoted, which, in turn, requires students to feel confident and respected.

In Christian's lessons, the social dimension of practices like explanation-building is implicitly introduced. Although Christian takes for granted what makes a good explanation without telling the students, they do participate in the process of selecting the keywords and concepts necessary to build the explanation. On the other hand, the elaboration of the explanation is a conjoint process where dialogue plays an essential role. Finally, students often share their explanations so that group members may provide with some ideas and comments on how they could improve them. That is, there is some negotiation on the construction of knowledge through practices in the classroom, although students do not decide what an explanation is and what its quality criteria are. This can be done because Christian sustains an environment in which students know their interventions will be welcomed with respect, valued, and considered. I was positively surprised to see students who had serious difficulties with English (because they were not native-speakers and had spent little time in the UK) participating in the activities voluntarily; in some cases, their classmates helped them express an idea, reinforcing the image of a community that learns together.

iii) *Patterns of discourse*. A widely supported idea is that classroom discourse is decisive in how students understand and conceptualise science (Christodoulou & Osborne, 2014) and learning (Plakitsi *et al.,* 2017). Thus, if teachers aim for their students to become familiar with science as a set of practices, they must carefully select the type of discourse used, since not all them reflect "the specialized ways of participating in science and (…) how ideas are validated and communicated within the scientific community" (Harris *et al*., 2012. p.771). Dialogic teaching environments are those in which teachers and students interact to elicit and coordinate their different ideas and perspectives (Alexander, 2008) to develop some collective thinking (Mercer, 2004). According to Mortimer and Scott (2003), "(t)he very act of conducting dialogic interactions in class serves to (…) demonstrate to students that it is perfectly legitimate for them to 'talk science' in this kind of way (questioning and discussing findings and ideas, rather than just accepting them)" (p.70). Therefore, teaching science-as-practice suggests using a classroom discourse with a predominance of dialogic interactions.

Despite the relevance of dialogic discourse for promoting students' engagement in epistemic practices, many studies show that dialogic interactions are usually absent from science classrooms (Wells, 1999; Harris *et al.,* 2012). Kumpulainen and Lipponen (2009) propose that this might be because managing the diversity of students' ideas is a highly demanding task for teachers. Harris, Phillips, and Penuel (2012) detail the reasons that make dialogic interaction challenging for teachers, highlighting that it requires i) deciding what use to make of students' ideas; ii) encouraging students to share their thinking; iii) knowing how to get students to listen to their classmates and respect their ideas; iv) being able to improvise and respond to students' ideas; v) integrate effectively students' everyday knowledge and practices, with the norms, scientific content and practices of science; and vi) knowing how to deal with students with different cultural experiences.

Christian manages to create a learning environment in which students have numerous opportunities to participate in genuine epistemic practices, such as the construction of explanations. Christian's classes are indeed very small, and this could facilitate the foundation of a climate of trust in which dialogue is always present. However, it does not mean that Christian does not also have some skills and strategies that help him in this task. For example, he has developed a teaching strategy to support students in the production of explanations. This strategy is composed of a series of phases. In the first one, Christian works in conjunction with his students to select a group of keywords and to recall some pertinent content knowledge. In the second phase, students must work individually to write their explanation. Finally, they share their product with a peer who will help them to enhance the quality of their explanation. Thus, we witness different interaction patterns in the same activity, two of them of dialogic nature. On the other hand, the analysis of the intervention sequences used by Christian reveals that these are varied and complex since they aim to elicit, develop, and connect the ideas of many participants. That Christian had a specific instructional strategy for the elaboration of explanations in the classroom makes him a very valuable case for my research.

CHAPTER 5. CROSS-CASE ANALYSIS: FINDINGS AND DISCUSSIONS

5.1. Overview

As reported in Chapter 4, Adrian, Becca, and Christian – together with Barney and Alba– provided singular cases of the interaction patterns between knowledge and beliefs put at work when teaching how to construct scientific explanations. Although each teacher is unique, several consistencies between certain aspects of their experiences could be glimpsed. I conducted a cross-case comparison to establish these commonalities and also the differences between them since, as Patton (2002) posits, "understanding unique cases can be deepened by comparative analysis" (p.56).

Some scholars contend that cross-case comparisons might decontextualise and, therefore, obscure, the particular cases (Molenaar, 2004). However, I found the analysis across participants highly valuable for my research purposes since it allowed me to explore themes I had not considered before (Yin, 1994), prompted new questions (Khan & VanWynsberghe, 2008), and helped me refine some concepts (Ragin, 1997). Moreover, given that this type of analysis entails the comparison from different settings, it provided some significant evidence for proposing improvements in teacher education and professional development experiences, which, eventually, might prop the modification of educational policies (Klenke, 2016).

In this chapter, I present, in form of assertions, five lessons learned about teachers' PCK of Scientific Explanation, based upon the cross-case analysis of the full dataset presented in the case profiles.

5.2. Assertion #1: Teachers display a multiplicity of meanings for 'explanation'

One of the first things I noticed while enrolled in my fieldwork was that, for the participant teachers, my operational definition of scientific explanation (§2.5.4) overlapped with many other meanings of the term 'explanation'. For the purposes of this research, it was essential to identify and clarify these varied meanings because, without attention to them, I could be observing how teachers promoted and supported some practices which, although legitimate, differ from what I understand by 'scientific explanation'. In the next section, I summarise the most relevant aspects related to how each participant understands 'explanation', and then I proceed to discuss these aspects to put them into perspective within the academic literature.

5.2.1. Meanings of 'explanation' identified among the participant teachers

Within each of the case profiles presented in Chapter 4, there is a section aimed at clarifying the knowledge that a particular teacher possesses about scientific explanation. In this regard, a couple of considerations caught my attention, because they were a constant in all participants: i) teachers possess multiple understandings of the verb 'explain'. These coexisting meanings were introduced in the classroom, so that when the teachers requested an explanation or posed a seeking why-question to the students, they did not always refer to the same thing, and did not expect the same type of answer; and ii) in the interviews, when questioned how they would characterise scientific explanations, the participants were not able to provide a well-defined response. Besides, their responses did not always match the meaning they enacted in their teaching practice, nor the sense in which it is used in this thesis, reform documents (Duschl, *et al.*, 2007; OECD, 2013), and science curricula (MECD, 2013; Department for Education, 2014; Ministry of Education, 2014; ACARA, 2015).

My analysis of the episodes in which the teachers posed *why-questions* or demanded their students to *explain* something led me to conclude that the practices in which students were supposed to engage differed from one episode to another, although it is possible to establish some commonalities between participants. We can categorise the set of meanings of 'explanation' granted by the sample teachers in two groups: explanations whose aim is making sense of a natural phenomenon –what I labelled as 'scientific explanations'– and explanations with a different aim –non-scientific explanations. In all participants, I found instances belonging to both groups (Table 5.2.a).

SCIENTIFIC EXPLANATIONS	NON-SCIENTIFIC EXPLANATIONS
*"If all bodies fall with the same acceleration, which is independent of their mass, **why** do we think that a stone and a feather do not fall with the same speed?"* (E#25-Ad)	*"Could you (…) **explain** the concept using an example?"* (E#9-Ad)
*"If we were spinning in a carousel with swings, we would be shot off. **Why?**"* (E#12-Al)	***Why** is it false? What is deformation?* (E#3-Al)
*"I don't know if you have noticed, but in the springtime, or in the summer, there are many fewer insects in a cloudy day than in a sunny day. **Why?**"* (E#1-Ba)	*Who knows how to **explain** this little dot here?* (E#13-Ba)
*"The temperature remains constant during a change of state. (…) **Why?**"* (E#3-Be)	*Can you **explain** how you came to the reasoning that you were saying?* (E#17-Be)
***"Why** is it that gases are even worse (than liquids) at conducting heat?"* (E#5-Ch)	***Why** are we gently heating it?* (E#13-Ch)

Table 5.2.a) Examples of scientific explanations and non-scientific explanations in the five participant teachers.

Within the category of 'scientific explanations', I established several subcategories, according to the type of account provided by the explainers. To begin with, all participants elaborated or requested causal explanations at some point. This result was to be expected because, as Rocksén (2016) affirms, it is very common that when a teacher or a student declares "to be able to explain something", this can be translated as that "[they] believe themselves to be able to formulate a causal relation between events, according to the local norms of form and content" (p.842). On numerous occasions within my cases, this type of explanation involved the description of the mechanisms responsible for the occurrence of the phenomenon. The causal/mechanistic explanation is, according to some authors, the most prevalent form of scientific explanation in science classrooms (Osborne & Patterson, 2011). When students are asked to explain phenomena, what is often expected is that they cite mechanistic properties relevant to their production. This seems reasonable if we consider the topics covered by science curricula at Secondary levels in both England and Spain, in which the connection between macroscopic (the observable) and (sub)microscopic levels (the unobservable) has a leading role (Chinn & Brown, 2000; Taber, 2013). Illustrations of this connection can be found in fragments 1.10 of the English National Curriculum, and 2.7 of the Spanish Curriculum for science in secondary school (Table 5.2.2, next section). Among my participants, both Becca (E#3-Be) and Christian (E#5-Ch) exemplify the use of causal/mechanistic explanations.

Another subcategory of scientific explanation I found in teachers' explanatory episodes is the anthropomorphic explanation. Adrian, Becca, and Christian utilise human attributes to explain properties and behaviour of non-human entities, such as particles in solids and fluids. There are two things about anthropomorphic explanations I consider interesting to note. The first is that, in all episodes in which this type of explanation appears, it is the teacher who provides it as part of an instructional explanation; that is, in none of my observations it is the students who choose an anthropomorphic explanation, despite what numerous studies indicate as more common (Gilbert *et al.,* 1982; Taber & Watts, 1996). The second is that they do not appear in the context of biological phenomena, which is where anthropomorphic explanations more often occur (Tamir & Zohar, 1991).

In Barney's biology classes (Appendix A.9, §A.9.3), I did find two examples of teleological explanation, though (see Table 5.2.c). In both cases (E#3-Ba and E#1-Ba), it is a student who formulates the teleological explanation; and in both cases, Barney overlooks them. As with anthropomorphic explanations, the role of teleological explanations in science learning has been the subject of extensive discussion. Many researchers argue that both types of explanation can serve pedagogical purposes. For example, Zohar and Ginossar (1998) claim that they may boost students' interest toward scientific topics, simplify causal/mechanist explanations and help students organise information in familiar terms. Treagust and Harrison (2000) suggest that teleological and anthropomorphic metaphors may reduce the complexity and the number of scientific concepts, thereby increasing students' motivation and facilitating the conveying of ideas. Helldén (2005) agrees that anthropomorphic explanations may have a positive effect on conceptual development. Adrian, Becca, and Christian use anthropomorphic explanations as a means to help the students with the task of understanding processes that require some background knowledge. By their gestures and the tone of their voice, it can be inferred that these explanations are just a way of speaking for these teachers, a formulation with pedagogical value, and not a legitimate way of reasoning. However, it would be pertinent to make this very clear to the students. Zohar and Ginossar (1998) even propose that learners should be engaged in explicit discussions about the significance of such formulations.

There are three types of scientific explanations I could find in the data collected from one case only. Barney demanded both evolutionary explanations and explanations whose aim was to make sense of a set of data (see §A.9.3). Evolutionary explanations are very common in Biology lessons, which is Barney's speciality, and may be characterised as answers to the question 'Why is something prevalent?' (van Mil *et al.*, 2013). For its part, the explanation of a set of data given in the form of a table or graph, is also crucial in the science classroom, being one of the competencies required by the OECD for scientific literacy (OECD, 2013). Regarding this practice, it is necessary to say that it does not only consist of describing, interpreting, or explicating the data, but in trying to find a scientific explanation as to why data are that specific way. Finally, in Alba's case, there is an instance of what I called 'phenomenological explanations' since the occurrence of a natural phenomenon is justified by its mere appearance in our experience (§A.8.3). In Table 5.2.b, I specify which of the different meanings of scientific explanation are found across the participants, while in Table 5.2.c, I provide an example for each of these meanings.

The discussed subcategories that emerged from the data analysis can be seen as different types of scientific explanations; that is, they all have the same object (a natural phenomenon) and the same objective (to understand why the phenomenon occurs), although how the narrative is constructed (the reasoning process) does not follow the same norms. This is not the case of explanations classified as non-scientific, since their objects, objectives, and elaboration processes are totally different[40]. Then, I would not talk in terms of *subcategories* but

[40] Hence the negative label.

of a *miscellanea of meanings* of the verb 'explain'. These meanings differ from what reform and policy documents consider as one fundamental aspect of scientific literacy, although some of them coincide with the meanings the Spanish science curriculum sketches (see §5.2.2). As with scientific explanations, it is possible to find similarities across participants.

Table 5.2.b) Summary of meanings for 'explanation' present in each participant's case.

TYPE OF EXPLANATION	ADRIAN	BECCA	CHRISTIAN	ALBA	BARNEY
SCIENTIFIC EXPLANATIONS					
Causal explanations	✓			✓	✓
Mechanistic explanations		✓	✓		✓
Anthropomorphic explanations	✓	✓	✓		
Teleological explanations					✓
Evolutionary explanations					✓
Phenomenological explanations				✓	
Sense-making of a set of data					✓
NON-SCIENTIFIC EXPLANATIONS					
Rich descriptions	✓				
Concept clarification	✓	✓			
Metacognitive explanations	✓	✓			
Sense-making of a set of data					✓
Justify a mathematical convention/ representation	✓	✓		✓	
Justify a procedure		✓	✓		✓
Justify an answer/belief	✓	✓	✓	✓	✓
Justify a result			✓		

The most extended meaning for 'explanation' across the cases is 'justification', understood as the process of providing reasons to believe that something is the case. All the case-study teachers use 'explanation' as 'justification' at a certain point in their practice. This conflating is not new; more than half a century ago, Scriven (1962) accused Hempel of confusing the facts that justify an answer to a why-question with the answer itself. Within my participants, the justification process refers, on some occasions, to an answer given by a student after having been questioned and, on others, to the result of an activity or experiment. Teachers also demanded justificatory explanations when trying to make students understand a practical procedure instead of simply following it. One meaning widely extended among the participants (found in Becca, Adrian, and Alba) is to *explain* a mathematical object or representation. This requires students to know the meaning of mathematical symbols and conventions about their use. In all the listed situations (Table 5.2.c), the object of the explanation is not a natural phenomenon, but something related to school science content.

Table 5.2.c) Different meanings for 'explanation' displayed by the five participants

DIFFERENT USES OF THE VERB 'EXPLAIN'		
Scientific explanation: Articulation of theoretical and empirical knowledge to make sense of a certain phenomenon through a process of reasoning		**Examples**
Causal explanations	Seek to identify the causal chains that clarify why a certain phenomenon is/has being/been produced.	***"Why has my speed changed? What have they done** to me when they pushed me?"* (E#8; Y9.O21-Ad)
Mechanistic explanations	"Decompose a system into its parts, ascertain their different contributions, and determine how these are integrated into a whole" (Levy & Bechtel, 2012, p. 244). They usually entail descriptions of processes at the atomic-molecular and cellular levels (Southard *et al*., 2017)	*"I want you to explain it to me **according to what happens to the particles"*** (E#11; Y10.O3-Be) *"**Why** is it that gases are even worse at conducting heat? **What is it about the structure of a gas, of the particles in gases**?"* (E#5; Y10.O1.P-Ch)
Anthropomorphic explanations	Account in which human characteristics, intentions, and agency is attributed to certain entities or inanimate phenomena to explain their behaviour.	*Ba.- **They are saying: 'I don't want to change. So, I will apply a force in order to not to change'**. (…) That's a possible explanation for the force of friction.* (E#10; Y9.O26-Ba)
Teleological explanations	"Describe actions, objects or processes which exhibit an orientation towards a certain goal or end-state" (Ayala, 1970, p.8)	*Ba.- The eggs hatch… the reproductive cycle of insects is organised in such a way that… why do they have it organised like that?* *S8.- **For not to die when it's cold*** (E#1; Y8.O1-Ba)
Evolutionary explanations	Account of how the phenomenon came to be, in the light of evolution and natural selection.	*S1.- Because that prepares you to become a mother or a father.* *Ba.- Ok, **that's the evolutionary sense**, but why does that change happen suddenly?* (E#7; Y10.O1-Ba)
Phenomenological explanations	Appeal to experience to justify that a phenomenon is actually the case.	*Al.- Does it exist a North pole alone and a South pole alone? (…) No.* *S1.- Why not?* *Al.- **Because that's what experience says*** (E#14. Y9.O5-Al)
Sense-making of a set of data	Seek to identify the causes or the mechanisms to explain the data or the pattern shown by a set of data.	*"Do you find any sense that in boys between 15 and 19 years the first cause of death is traffic accidents, and in girls, the first cause of death is suicide?"* (E#14; Y10.O6-Ba)

Table 5.2.c) Different meanings for 'explanation' displayed by the five participants

DIFFERENT USES OF THE VERB 'EXPLAIN'		
Non-scientific explanations		**Examples**
Rich descriptions	Describe an occurrence, or the events preceding a phenomenon, but do not discuss how these events are related to each other in bringing it out.	*Ad.- Could you* ***explain what's happening here?*** *What are we talking about?* (E#27; Y9.O7-Ad)
Concept clarification	Elucidation/Interpretation of the meaning of a term.	*"Have you read 'trajectory'? And what is 'displacement'? Those* ***two concepts*** *are related, and* ***we are going to explain them now****"* (E#18; Y11.O4-Be)
Metacognitive explanations	Elucidation of the reasoning or the steps followed to find a solution or achieve a result, during its development or after finishing.	*Ad.- Could you* ***explain what you have done****?* (E#1; Y9.O1-Ad)
Sense-making of a set of data	Seek to identify some historical events to explain the data or the pattern shown by a set of data.	*Ba.- Can anyone give me* ***an explanation for the second descent****?* *S3.-The Spanish civil war*. (E#13; Y10.O4-Ba)
Justify an answer/belief	Provide the reasons that support an answer/ belief and that form the basis for its evaluation.	*"I want you to tell me if the first answer is correct or not, and* ***the reasons why you have made that decision"***(E#4; Y9.O9-Ad) ***"Why do you consider it important that you can seed lettuces at any time?"*** *(E#6; Y8.O8-Ba)*
Justify a result	Provide the reasons that makes understandable the result of an activity or operation and that form the basis for its evaluation	*"Now, the question is:* ***why are they not all the same?"*** (E#8; Y9.O1.C-Ch) *"****Why is there not a match between the data we find in nature and the numerical ideal we already know?"*** (E#16; Y11.O5-Ba)
Justify a procedure	Provide the reasons that support a set of actions and that form the basis for their evaluation	***"Why do we have to do that?"*** (E#2; Y8.O1-Ba)
Justify a mathematical convention/ representation	Provide the reasons/norms that justify why a mathematical convention/ representation is the case.	***"Why does only time appear at this angular velocity?"*** (E#26; Y11.O7-Ad)

Both Adrian and Becca use 'explain' as a synonym for 'clarifying a concept' (e.g., E#9-Ad and E#18-Be). In these ocassions, what they expect is that students make an assertion/definition of a technical term, and then, to develop or extend its meaning (Norris *et al*., 2005). These two participants also ask for metacognitive explanations, where students must elucidate their reasoning to achieve a certain result, while solving a task or after finishing it. Adrian and Becca use metacognitive explanations as an assessment tool. When a student makes explicit the steps followed to find the solution/answer for a problem/task, it is easier to find conceptual and thinking errors and to comment on them for the rest of the class, which is what they usually do. In Adrian's case, 'explain' as a synonym of 'describe' is also found. It is surprising that, despite being this the most extended sense in which 'explain' is used in the Spanish science curriculum (§5.2.2), it appears only in one of the Spanish participants. Finally, in Barney's case, 'explain' is used as 'explicating a set of data' that do not require a scientific explanation (see §A.9.3).

The assortment of meanings deployed by the participant teachers made me wonder about two things: first, if teachers themselves are fully aware of this multiplicity of uses; and second, if they have a discernible notion of what it means to construct a scientific explanation in the sense that academic and reform documents allude. To solve these queries, I purposely asked them in the interview what they understand by an explanation *in science*. Interestingly, Barney recognised this as a non-trivial question –"*not everyone thinks the same about what a scientific explanation is. Even if you search on the Internet what the official notion of scientific explanation is, not everyone agrees"* (I-Ba, §A.9.3). Becca seemed a bit confused with this question, asking me back, "*but an explanation, let's say, traditional, where a student poses a question and I explain to her why this is that way?*" (I-Be), which suggested that she might be considering more than one meaning. I, then, highlighted the word 'scientific', so that Becca oriented and structured her answer more confidently. The other three participants simply took this question as one more within the interview. After analysing their responses, I concluded that they were not able to articulate a characterisation of scientific explanation that matches the operational definition of this dissertation (§2.5.4); as usual in my study, Christian was the exception.

Alba said that in laboratory reports and students' presentations, she asks them "*explain what (they) have done*" (I-Al). In another moment of the interview, Alba affirms *"(w)ell, I am a teacher, I like explaining*" (I-Al), which seems to mean that she likes giving representations and reasons to make ideas and concepts understandable for her students (§A.8.3). In this dissertation, I refer to this practice as 'explication', to establish a clear distinction with my operational definition of scientific explanation (§2.5.4). Other authors refer to this as 'instructional explanations' (Gage, 1968), or 'science teaching explanations' (Marzabal *et al.,* 2019) since they are intended to present concepts and procedures in a learning situation, transcending a merely informative purpose and looking to trigger students' comprehension (Leinhardt, 2010; Talanquer, 2007). Although in her instruction Becca makes use of different senses for the voice 'explain', when asked explicitly in the interview, she also replied in terms of explications.

Adrian, on his part, conflates 'explanation' with both 'explication' and 'argumentation' in his response:

> *"Explaining something requires a great effort from teachers, because it is not the same to explain, for example, the law of gases to a Year 10 student than to explain them to a Year 12; it is completely different. They start from totally different basis, they start from totally different previous knowledge… they possess ideas that have to be broken and that are very difficult to break… so, you have to think about the way of arguing in an efficient, sufficient, and simple way so that they understand why their previous idea is not true and the current idea is what is really true."* (I-Ad)

For Barney, the elaboration of a scientific explanation is the final stage within the scientific method, which requires sharing with other people what have been learnt and to make it understandable (§A.9.3). –"*the end of the project was to narrate everything they had done, in the scientific format, eh, …, to explain to the rest of the class what they had found during their investigations and how it had been solved*" (I-Ba). A few lines later within the same interview, Barney again identified scientific explanations as descriptions of students' investigations – "*Imagine* [the time it takes] *30 pupils explaining what they are doing*" (I-Ba).

Finally, when Christian was asked in the interview what a scientific explanation is, he said it is an activity in which scientists use some ideas and specific language to explain why something happens. He is, then, the only participant that talks about scientific explanation in terms that fits the operational definition for this dissertation.

5.2.2. Discussion

Researchers, educators, policy makers, and curriculum designers agree that equipping students with the competence to construct scientific explanations is critical for achieving scientific literacy (Ryder, 2001; Bybee *et al.*, 2009). The OECD (2013) recognises only three practices in which students should acquire proficiency to be considered scientifically literate; being able to provide explanatory accounts for natural phenomena is one of them. Similarly, the

National Research Council (Duschl *et al.,* 2007) asserts that students who are proficient in science can use and interpret scientific explanations of the natural world and are able to generate and evaluate their own scientific explanations.

Table 5.2.2) Instances of the verb 'explain' in the Curriculum for England (NCE, 2015) and the Spanish Curriculum (MECD, 2013). Emphasis added

National Curriculum for England, Science KS3 and KS4 (NCE, 2015)	Spanish Curriculum for Science at Secondary school level (LOMCE, 2015)
PUPILS/STUDENTS SHOULD…	
1.1. "Be encouraged to understand how science can be used to *explain* what is occurring, predict how things will behave, and analyse causes" (KS3, p.2)	2.1. "*Explain* the fundamental processes of nutrition, using graphic schemes of the different systems involved in it" (Y7-Y9, p.208)
1.2. "Be encouraged to relate *scientific explanations* to phenomena in the world around them and start to use modelling and abstract ideas to develop and evaluate *explanations*" (KS3, p.3)	2.2. "Recognise and *explain* what mutations consist of and their types" (Y7-Y9, p.208)
1.3. "Understand that science is about working objectively, modifying *explanations* to take account of new evidence" (KS3, p.3)	2.3. "Know and *explain* the components of the digestive, circulatory, respiratory and excretory systems and how they work" (Y7-Y9, p.208)
1.4. "(Be taught to) present reasoned *explanations*, including *explaining* data in relation to predictions and hypotheses" (KS3, p.4)	2.4. "Analyse and compare the different models that *explain* the structure and composition of the Earth" (Y7-Y9, p.212)
1.5. "(Be taught about) the mechanism of breathing to move air in and out of the lungs, using a pressure model to *explain* the movement of gases, including simple measurements of lung volume" (KS3, p.6)	2.5. *"Explain* the mechanism of nerve impulse transmission" (Y7-Y9, p.216)
1.6. "(Be taught about) using physical processes and mechanisms, rather than energy, to *explain* the intermediate steps that bring about such changes" (KS3, p.10).	**2.6. "Formulate hypotheses to *explain* everyday phenomena using scientific theories and models"** (Y8-Y9, p.258)
1.7. "(Be taught so that they develop understanding and first-hand experience of) using scientific theories and *explanations* to develop hypotheses (KS4, p.5)	2.7. "*Explain* the properties of gases, liquids and solids using the kinetic-molecular model" (Y8-Y9, p.259)
1.8. "(Be taught so that they develop understanding and first-hand experience of) explaining everyday and technological applications of science" (KS4, p.5)	2.8. "Distinguish between hypotheses, laws and theories, and *explain* the processes that corroborate a hypothesis and endow it with scientific value" (Y11, p.263)
1.9. "(Be taught so that they develop understanding and first-hand experience of) using a variety of concepts and models to develop scientific explanations and understanding (KS4, p.5)	2.9. "*Explain* the Celsius scale by setting the fixed points of a thermometer based on the expansion of a volatile liquid" (Y8-Y9, p.262)
1.10. "(These ideas include) these periodic properties can be explained in terms of the atomic structure of the elements (KS4, p.11)	2.10 "*Explain* the reasons why carbon is the element that forms the greatest number of compounds" (Y11, p.264)
1.11. "(These ideas include) the concept of cause and effect in *explaining* such links as those between force and acceleration, or between changes in atomic nuclei and radioactive emissions" (KS4, p.14)	2.11. "Reasonably *explain* the utility and limitations of the ideal gas hypothesis" (Y11, p.268)

Many countries incorporate into their curriculum the goal of achieving students' competence in explaining natural phenomena (e.g., Spain (MECD, 2013); Engand (Department for Education, 2014); Singapore (Ministry of Education, 2014); and Australia (ACARA, 2015)). Since teachers are generally guided by official curricula and standards, examining these documents can give us some clues to understand the point from which they start when thinking about this curricular goal. Without purporting to conduct a thorough textual analysis, I have selected some fragments from both the Spanish and the English science curricula to illustrate how scientific explanation is conceptualised in these documents.

In the National Curriculum for England (NCE, 2015) for KS3 and KS4 (Year 7 to Year 11), the word 'explain' appears 11 times in total. Those excerpts that refer, to a greater or lesser extent, to explanation as a practice in which students should actively engage are in bold in Table 5.2.2 (left column). For example, in fragment 1.2, it is established that students must "develop and evaluate explanations" –epistemic dimension (Duschl, 2008)– while in 1.4, it is said that they must "present reasoned explanations" – social dimension–. In fragment 1.9, explicit mention is made of the need for students to experience "first-hand" the use of "a variety of concepts and models to develop scientific explanations" –conceptual dimension–. That is, scientific explanations must be developed, communicated, and evaluated by students in the classroom.

Something interesting to highlight from the selected extracts is that, in them, the four basic elements that a scientific explanation should have –according to the PTDR model (Yao *et al.,* 2016)– are mentioned. In 1.2, it is stated that explanations must be related "to phenomena in the world" –the 'phenomenon component' in the PTDR model–. In 1.9, it is established that students must use "concepts and models" to elaborate their explanations –the theory component–. In 1.3, it is remarked that explanations in science must be "modified to take account of new evidence", while in 1.4, they say that pupils should "explain data" –the data component–. Finally, in the same fragment 1.4, it is established that the explanations must be "reasoned"; in 1.6, the explanatory power of "processes and mechanisms" is recognised; and in 1.11, the cause-effect relationship is required as the basis for explaining some kind of phenomena –all of which refers to the reasoning component–. If all these fragments are taken together, a notion of scientific explanation may be sketched. This could help science teachers get an idea, although fuzzy, of what they are supposed to understand by 'explaining' in this document. Fragment 1.10 –in which it is said that some properties of chemical elements can be *explained* in terms of their atomic structure– is an exemplification of this notion in action. The verb 'explain' is used quite consistently throughout the English science curriculum, then, insisting on the idea that concepts, models, and theories can be "used to explain what is occurring".

The problem that arises in the case of the science National Curriculum for England is that, although all components of the PTDR model are somewhat present, they are mentioned very briefly and in different places, without clarifying what role each of these components plays in the process of constructing the explanation, nor the potential relationship between them. The responsibility of articulating these seemingly unconnected pieces in a single coherent construct that can be implemented into the classroom is left to the teacher, which may lead to very different outcomes. The transition from what curriculum designers prescribe should happen in the classroom (the so-called 'intended curriculum') to the enactment of instructional practices (the implemented curriculum) requires a process of interpretation and sense-making by teachers (the interpreted curriculum (Van Den Akker, 1998)). This process is mediated by their knowledge, beliefs, experience, and intentions (Osborne *et al.*, 2002; Aikenhead, 2006; Jin *et al.*, 2017), so that the task of understanding and implementing what curricula state about explanations is not straightforward.

The interpretation of what the curriculum designers mean by 'explain' seems even more complicated for Spanish science teachers who take the LOMCE (MECD, 2013) as their starting point (Table 5.2.2, right column). From the science curriculum for Secondary students, I selected 11 fragments, among which I could identify at least three different meanings for 'explain'. The meaning I have been using for this thesis, which coincides with the one that policy makers, educators and researchers deploy (see §2.5.4), is well captured in fragment 2.6, according to which students should "formulate hypotheses to explain everyday phenomena using scientific theories and models". Only this excerpt is in bold because it is the only one that portrays the elaboration of explanations as an epistemic practice[41]. Here, both the phenomenon component and the theory component are explicitly introduced. Excerpts 2.4 and 2.7 are illustrations of the explanatory role of models in science. The word 'formulate' –fragment 2.6– might allude to the structured elaboration of an explanation, which could be related to the reasoning component,

[41] I acknowledge that we must be somewhat cautious with this statement because, being rigorous, explanation is not conceptualised as such in the Spanish curriculum (MECD, 2013) since science is not discussed in terms of epistemic practices. At best, they use the terms 'scientific activities' and 'inquiry skills.' Similarly, in the UK National Curriculum (Department for Education, 2014), the phrase 'scientific practices' is not used at any time. They talk about "experimental skills and strategies" to refer to goals related to scientific inquiry. As argued in Section 2.3, the move from science-as-knowledge towards science-as-practice was much more than a mere change of terminology. This shift had as very deep roots as their epistemic and educational consequences (more on this topic in García-Carmona, 2020).

but this is not clear. Neither in this, nor in any other fragment in the whole document, is the data component mentioned as one of the essential pieces to construct scientific explanations.

The latter is not the most frequently repeated meaning for ‘explanation’ in the Spanish National curriculum, though. In six of the eleven selected fragments, ‘explain’ could be replaced by ‘describe’ without changing the meaning of what is being requested. Thus, when it is said that students should be able to *explain*, they mean that students should be able to *describe/explicate*, for example, a system and its functioning (excerpt 2.3), a process (2.1; 2.8), a concept (2.2), a mechanism (2.5), and the origin of a measurement scale (2.9). Many more examples in which ‘explain’ is confused with ‘describe’ can be found in the Spanish curriculum, for Physics, Chemistry and Biology (see MECD, 2013). While I acknowledge that it is important to engage in these rich descriptions to learn about processes and concepts, the kind of understanding provided by the practice of building scientific explanations that account for natural phenomena involves more than mere descriptions, since these lack the causal-mechanistic connection between elements. Finally, fragments 2.10 and 2.11 in this document do not either seem to capture the sense of my operational definition of ‘scientific explanation’ (§2.5.4). Explaining the limitations of the model of an ideal gas could be conflated with being able to merely list these reasons for justification.

This rough compilation of excerpts allows us to perceive that the Spanish curriculum does not provide a complete, clear, and unique conceptualisation for the term ‘explain’. Therefore, the cognitive effort that teachers must make to grasp what it is to build a scientific explanation is significantly higher. Since conceptual clarity is the first step towards effective instructional practices (Braaten & Windschitl, 2011), the lack of an articulated conceptualisation about its nature and epistemic criteria may become an obstacle for teachers to systematically teach how to build explanations (Russ *et al*., 2008).

Scientific explanation as is characterised for this research is a quite specific science discursive practice, with well-defined conceptual, epistemic, and social dimensions (Duschl, 2008). This practice-based conceptualisation is not so evident in science curricula, since issues such as the norms that must be followed to develop an explanation, the quality criteria to judge explanations, or the level of proficiency students must achieve to be considered competent, are not specified. In the Spanish Curriculum, to all this, we must add that the term ‘explain’ appears with a multitude of meanings not explicitly clarified.

If we look up for the word 'explain' in the Oxford Dictionary[42], the definitions it provides are the following: a) Make (an idea or situation) clear to someone by describing it in more detail or revealing relevant facts; b) Give a reason so as to justify or excuse (an action or event); c) Be the cause of or motivating factor for; and d) Minimise the significance of an embarrassing fact or action by giving an excuse or justification. Perhaps the reader recognises the first three meanings as some of those used by my participants in their lessons. Being consistent with the coding followed throughout this thesis, these definitions may be identified to what I have called *explication* (a), *justification* (b) and *causal explanation* (c).

Many authors have reported on teachers' meanings of 'explanation', with varying degrees of comprehensiveness. Beyer and Davis (2008), for instance, analyse one novice elementary teacher's understanding of explanation. They inform that the teacher displays two different meanings in her lessons: one that fits my operational definition (§2.5.4) and another that alludes to the everyday meaning of 'explication' (a). Koballa, Crawley, and Shrigley (1988) had already noted this distinction between 'explaining a thing' and 'explaining a thing *to someone'*. According to them, the former is a disciplinary practice, while the latter is a pedagogical activity. Seah, Clarke, and Hart (2011) agree on this distinction, but they do not talk in terms of *meanings* of explanation but different *uses* of explanations. Among pedagogical uses, they include 'terms/phrases clarifications' and 'detailing practical procedures', which is something my participants did. Among the scientific uses, Seah and collaborators mention theoretical explanations (in which a theory like, e.g., the particle theory, is used to provide an account of a natural phenomenon) and conceptual explanations (in which a concept, such as mass, is alluded). However, they do specify what the basis for such distinction is and/or why it is relevant.

In her single case study about conversational structures in science classrooms, Rocksén (2016) lists three meanings for the word 'explanation' that one teacher enacted during a set of lessons about biological evolution. These three meanings –which included i) the everyday sense; ii) a pedagogical-professional meaning; and iii) the scientific meaning of the word explanation (p.842)– co-existed and overlapped during the sessions. Braaten and Windschitl (2011), in their typology about teachers' explanations, cite 'explanation as justification' (b), and 'explanation as causal connection' –meaning (c) of the Oxford Dictionary, to which they add the elucidation of the steps taken to solve a problem/activity (what I have called 'metacognitive explanations'), and the unpacking of the meaning of a term ('concept clarification'). Norris *et al.* (2005) extend

[42] https://www.lexico.com/en/definition/explain

this typology to include ten categories, although they do not make a clear distinction between different meanings to the verb 'explain' (e.g., descriptions and justifications) and different types of scientific explanations (which depend on the reasoning pattern used; e.g., causal and functional explanations).

Since classroom talk is an extension of everyday language, it is not surprising that the polysemy of the word 'explain' sneaks into teachers' discourse. However, this should warn us about one fact; if curricula developers do not clearly specify what they mean when it is said that students must be competent in constructing explanations, teachers may have difficulties interpreting what they are requested to do. Moreover, teachers could ask students for explanations, convinced they are fulfilling the stated curricular objectives, when they are actually promoting and evaluating other practices. This confusion is present in the classical work of Coleman (1998). This author analysed the effects of scaffolding pupils' explanations as part of a study on learning in problem-based science classes. Although some of the examined responses certainly correspond to what we understand here as scientific explanations, many others were justifications for a certain belief or answer. The types of prompts used in both cases differ markedly. Therefore, it cannot be said that the same teaching practice was being analysed throughout the entire study.

McNeill and Krajcik (2012) warn that students also have a plethora of conceptualisations about explanation (usually understood as rich descriptions and explications). This may condition the way they answer an explanatory request (Berland *et al.,* 2016). So, when asking students *to explain something*, teachers should always specify the kind of response they expect from them. Seah, Clarke and Hart (2011) report a case to exemplify this fact. Mr. Gardiner was an experienced science teacher who asked his students to write an explanation about the phenomenon of thermal expansion. The analysis of the students' responses revealed that these had interpreted the task in different ways, which could be framed under the two meanings of explanation that the teacher had been using during his lessons. That is, what Seah and colleagues venture is that Mr. Gardiner's multiplicity of meanings for this word could have hampered students' understanding and decisions about the kind of answer that would count as an explanation. Rocksén (2016) claims that teachers need to become aware of the plurality of meanings of 'explanation' that they put into practice in the classroom; this, she argues, would lead them to plan learning experiences with a clearer purpose, which, eventually, would be beneficial for the students.

It is worth asking what degree of self-awareness should be required of teachers. As I reported, my participants show no explicit sign of being aware of the wide variety of meanings they attribute to the verb 'explain'. So, on many occasions, they simply ask the students to *explain something*, without making it clear what kind of response they expect. We have just seen that lack of clarity can condition how students understand and approach the task. In one of Becca's lab sessions, we found a very illustrative example. In the said session, students must experiment with different methods of separating solutions and mixtures. Before starting, Becca reads and discusses with the students the rubric that she will use to assess their work:

> *"You have, as always, the rubric. We're going to look at it for a little while, before we start doing anything, okay? (...) There are only two points: content –the work is excellent if it contains all the required points and these are* ***explained with clarity and accuracy****–; and image inclusion –it's excellent if real images of the process are included (...). Then, with respect to the content, it will be fine if the work contains all the required points,* ***but they are not explained with the clarity or the necessary accuracy****. Images of most processes are included, but not all. It is not so good if the work contains the required points,* ***but the explanations are wrong, that is, you have said something that is not right. It is not that the explanation is not very clear, it is that what you say is wrong.*** *Real images are included. And it is a fail if the work does not contain all the points, or does not include images, okay?"* (Y9.O8-Be).

Although Becca's intention is for students to know in advance what dimensions will be assessed so that they can act accordingly, the way the rubric is written does not clarify what she means when she says 'explain the points with clarity and accuracy'. Do they have to describe in detail what they have done and how? Should they justify why they have followed those steps and not others? Should they give a causal-mechanical explanation of the observed phenomena or simply be able to narrate the whole process to their classmates so that they understand it? Becca leaves too much room for student interpretation. The level of specification of the quality assessment criteria are also rather vague –how much accuracy is *sufficient*?– although Becca's comment about wrong explanations could give the students some clues as to the type of response they should elaborate.

We can find episodes that present a similar ambiguity about the meaning put at stake in all my participants (e.g., in Episode #4, Christian asks '[c]*an you try to explain that*?', and Barney in Episode #8 asks '[h]*ow would you explain that?*'). In her single case study, Rocksén (2016) alleges that the way in which the teacher and the students sequence their utterances and use gestures and emphasis in their dialogical interactions may help them distinguish what specific meaning of the word 'explanation' is being used. Based on the dialogical analysis carried out with each of the explanatory episodes found (§4.3.1.4, §4.4.1.4, §4.6.1.4, §A.8.4, and §A.9.4) we can, indeed, notice how, in most cases, discursive moves (especially, Initiating, Continuing and Reinforcing moves), as well as teacher-student interaction patterns, favour the disambiguation of the meaning of 'explanation' or the type of why-question that is being used/demanded in the activity. This allows students to frame their responses according to what they think the teacher wants. In Episode #14, for instance, Adrian launches the following questions: '*Could you give me an explanation for the gravity'*? Obviously, without a context, this question can be answered in several different ways (this is indeed an interesting pragmatic aspect of why-questions). Within the context of Adrian's lesson, however, he may also be referring to diverse things (Is he asking for a justification for a change in gravitational strength? For a description of how a numerical value of gravity has been obtained? Is he asking for what causes gravity? Or about what does Newtonian theory tell us about the origin of gravity?). Adrian specifies that what he is looking for is a clarification of the term: '*What do you think the gravity is?'* (E#14-Ad). As the other participants do in similar cases, he uses language in a particular way to guide the student towards the type of response desired.

The problems associated with a confusing proliferation of meanings of 'explain' is not merely semantic (Braaten & Windschitl, 2011), though, but may have consequences for learning. If educators and stakeholders expect teachers to incite and guide students to make shifts from descriptions, justifications, and explications to scientific explanations in their classes, it will be necessary to i) "identify teachers' understandings of scientific explanation (…) to uncover possible strengths upon which teachers can build as well as possible limitations in their understandings that may need to be refined" (Beyer & Davis, 2008, p.405), which is something I did; and ii) "provide teachers with more guidance about the nature of scientific explanations and more insight into how to generate and evaluate scientific explanations" (Braaten & Windschitl, 2011, p.640), which is an enterprise yet to be done.

5.3. Assertion #2: Despite being identified by teachers as an essential scientific practice, explanation construction –as it has been operationalised for this dissertation– is rarely purposely integrated into instruction.

One of the big questions that philosophers of science (along with thinkers from other disciplines) have tried to answer concerns the motivations and objectives for doing science. According to Machamer (1998), "(m)ost philosophical reflection about the aims and goals of science deals with the acquisition of knowledge and how that knowledge brings understanding. (…). This way of looking at science takes its goal to be explanation" (p.3). If generating explanatory accounts of the world is accepted as a fundamental goal of science, it is comprehensible that so many science education researchers and curriculum designers had assumed this practice as an indispensable piece for scientific literacy (§2.5.1 and §2.5.3).

A question that arose when I was reading academic papers and reform documents was whether in-service science teachers do also consider that students being able to explain natural phenomena is a central educational objective. I found this question fundamental since, in the end, it is the teachers who are responsible for designing materials, activities and strategies to support learners on their way towards proficiency in this practice. And, as research has shown, teachers are reluctant to implement any practice that clashes with their beliefs system and orientations towards science, teaching and learning (Höttecke & Silva, 2011; Robinson, 1969).

Moved by this concern, in my interviews, I asked the participants what they believe the motivations and objectives of scientists are[43]. Becca highlighted that scientists "*observ(e) everything and try to explain why*" (I-Be); for Christian "*what science fundamentally seeks is to explain natural phenomena*" (I-Ch), and Alba said that scientists *"try to explain why things happen*" (I-Al). Neither Adrian, nor Barney, mentioned explanation production as one of the fundamental objectives of scientists. For the former, scientists are devoted to *reading papers* and *conducting experiments to draw conclusions* (I-Ad), but he does not specify what the ultimate purpose of this is. Barney, who recognises that science allows us to construct informed knowledge about the world, does not mention explanations explicitly, just saying that scientists *raise hypotheses* that *the community must then validate* in some way. However, when asked directly for the role that explanations play in science, Barney acknowledged that "*building explanations is an aspiration of scientists*" (I-Ba).

As seen in Chapter 4, the degree of students' engagement in explanation construction that the sample teachers managed to achieve varied remarkably; in most cases, though, this level remained low. Almost fifty years ago, Martins (1972) claimed that learning how to produce explanations requires guided practice from teachers. Knowing that effective guidance demands great effort (Newton *et al.,* 1999; Yao *et al.*, 2016), I wondered whether the participants teachers considered the construction of explanations a practice valuable enough to make the effort worthwhile. My five participants display a wide range in the value they assign to the formulation of explanations in the classroom. Adrian openly admits that fostering students' explanatory skills is not a priority for him. Becca thinks students should be encouraged to build explanations as a way to emulate scientists in one of their most fundamental practices. For Christian, learning to

[43] The reader may remember that the participant teachers were not fully aware of my research focus.

explain is crucial for science learners, because it allows a deep interaction with, and an understanding of, natural phenomena. Besides, it may foster students' thinking, the other of his main learning objectives. In her interview, Alba says she does find it important to promote students' proficiency in explaining things, but she is actually referring to students' ability to *explicate* and communicate ideas (see §A.8.3), so the question remains moot. Barney conceives explanations as the final stage of the scientific method and so, he defends, it is a practice in which students should acquire proficiency (see §A.9.3). Becca and Christian seem to be the most interested in the practice of explanation building as an educational goal, being also the two participants in which I found something that could be considered as a practice-specific instructional strategy (see Figures 5.4.1.b and 5.4.1.c). Only Christian applied his strategy frequently and consistently.

In their single-case study, Beyer and Davis' (2008) found that proficiency on explanation construction was not a fundamental goal for the teacher they were investigating and, therefore, the opportunities she created for her students to learn about this practice were scant. Something similar has been found with other epistemic practices. For instance, many researchers have analysed the influence that teachers' beliefs about argumentation have on their instructional decisions (e.g., McNeill & Krajcik, 2008; Zangori & Forbes, 2013; Zangori *et al.,* 2013). Sadler (2006) shows that although secondary pre-service science teachers recognise the importance of argumentation, they tend to deem it as a pedagogical strategy for achieving other instructional ends rather than as an aim itself. Sampson and Blanchard (2012) found that teachers who value argumentation but hold some doubts about its potential to improve conceptual learning, are unlikely to incorporate argumentation into their classes, unless they count with a great deal of support. Similarly, Demirdöğen and Uzuntiryaki–Kondakçi (2016) found that teachers' beliefs about NOS are not translated into their instruction when they are not explicitly included among their goals of science teaching.

Other studies about science teachers' beliefs focus on the relationship between teaching practice and teachers' general conceptualisation of science. The pioneering studies of Brickhouse and collaborators (Brickhouse & Bodner, 1992; Brickhouse, 1989, 1990) expound how teachers' epistemological assumptions about science shape lesson planning and classroom practice. Crawford (2007) asserts that teachers' beliefs about science are "a driving force" towards "innovative instruction" (p.637), but Lederman and Zeidler (1987) notes that possessing some proper conceptions of what science is may not be sufficient for modifying teachers' instructional behaviour. Tsai (2002) delves into this line and argues that the degree of coherence between teachers' beliefs about science, about how to teach science, and about how students learn science is the most relevant factor for shaping performance.

Aware of this potential connection between assumptions about science and teaching practice, I framed the question about the objectives of scientists within a broad set of questions aimed at capturing how my case-study teachers conceptualise science. Each participant gave a very different answer to what science is (Table 5.3). Based on these responses, it is not possible to find any pattern that may lead to a clear statement about how likely it is that they include the production of explanations on their lessons. It may be said, though, that Adrian's classes are very unlikely to be focused on practice (and, thus, to situate the formulation of explanation as one fundamental goal) since he clearly adheres to a 'science-as-knowledge' approach. Jones and Carter (2007) show that conceiving science as a body of knowledge led teachers to favour low-cognitive demanding instructional strategies, among which explanations have no place; this is something I indeed noted in Adrian's practice (§4.3.1.3).

Table 5.3) Participants' characterisation of science

	SCIENCE CHARACTERISATION: SCIENCE IS…	
ADRIAN	A body of knowledge	*"(Science is) a body of knowledge about the dynamics in our world, which enables us to interpret what happens around us."* (I-Ad)
BECCA	A source of curiosity and answers	*"(S)cience is like (…) the engine that moves everything in the world; (it's) what awakens curiosity in the human beings and push them to want to know more. So, it seems to me that the human beings, with their curiosity, ask questions and demonstrate them through science, and that is what causes new questions to arise, and the process to start again…"* (I-Be)
CHRISTIAN	NR/DK	*"Honestly, I don't think I'm capable of answering or defining what science is." (I-Ch)*
BARNEY	A method to understand reality	*"Science is the method that human beings have developed to (…) find a way to approach more, without that being the absolute certainty, to understand everything that happens (…) in the whole universe." (I-Ba)*
ALBA	A way of conceptualising reality/life	*"For me, Science is everything; it is a way of life. I mean, I think people who are scientists see life in a very different way from the one who is an artist, or who is a philologist. For me it's that. It is a way of life."* (I-Al)

Another set of beliefs that may impact the decisions teachers make about what to include in their lessons are those concerning the nature of teaching and learning. This set of beliefs acts as a filter and organiser of information (Knight-Bardsley & McNeill, 2016) and, therefore, helps teachers interpret any request from curriculum designers. Brown (2009) states that since teachers base their classroom decisions on these beliefs, a conflict between different goals could become a *de facto* barrier to the introduction of educational reforms. The participants' beliefs about teaching and learning could provide, then, some clues about the promotion (or the lack of it) of explanation episodes in the science classroom.

In his interview, Adrian claims to have a constructivist conception of learning, although he acknowledges the difficulties of translating this into his classes due to some constrictions of the Spanish education system. He declares that the role of the teacher should be to facilitate the creation of knowledge, although in many occasions, he describes the teacher as a mere transmitter of knowledge; this last fits better with the teaching approach I observed in Adrian's classes. Alba also said she perceived a high degree of contradiction between her ideas and beliefs about how students learn and how science should be taught, and what she can eventually implement in the classroom given the available resources. So, like in Adrian's lessons, the opportunities for Alba's students to participate in authentic practices –where they could share and discuss their ideas with classmates and articulate their knowledge to create explanations– are practically non-existent (see §A.8.1).

For Barney, the teacher is responsible for promoting the necessary conditions for learning to happen, which includes confidence in students' ability to work, respect for them as individuals with valid ideas and interests, and opportunities to freely express and share these ideas with the group (see §A.9.1). Barney believes that when students are in an environment like this, they can get involved in learning in a much more profound and meaningful way. Barney, just like Becca, also argues that students learn better in collaboration with each other. Both social and emotional factors of learning are vital to Barney. Becca has a similar conception of the teaching-learning process, about which she emphasises the importance of actively involving the student and considering their prior knowledge and ideas. The teacher, she says, is a facilitator of the learning process, which must be mainly led by the student.

Finally, Christian believes that students should have as direct contact as possible with the phenomena they are intended to learn about. Christian lessons, then, have an eminently practice-based orientation. For him, it is also essential that students can communicate and exchange ideas, as well as having opportunities for reflecting on their own knowledge. Christian is continually proposing activities that reflect these dimensions of learning science.

We see that all participants believe that students should be the point on which a science class pivots, although the degree to which they can develop this belief, as well as how they put it into practice, is quite different. This has a direct impact on the importance that epistemic practices acquire in their respective classrooms. Alba and Adrian recognise that it is very difficult to translate their beliefs about how science should be taught to facilitate meaningful learning into practice; this results in the creation of teacher-centred learning environments, where the students' role is limited to following teacher's guidelines. Given that the students' ideas do not seem relevant for the development of the lesson, it is not usual to see episodes in School-A where the students explain a phenomenon.

In Becca, Barney, and Christian's cases, there is a greater degree of coherence between their beliefs and their actions; this might be due to their higher teaching experience. These participants' social conception of learning is exposed in the creation of opportunities for students to share and discuss their ideas with their classmates, and to solve tasks and problems together. In addition, the learning environments that Becca, Barney, and Christian promote allow deeper reflection by students, which opens the door to activities of higher-order cognitive demand. Since the construction of explanations is a social process that requires considering different pieces of knowledge to be organised within a coherent explanatory structure, students need to be given time, guidance, and resources to think, reason, share, and reflect about their own and their peers' ideas. The most complex episodes of explanation co-construction observed did happen in these three teachers' lessons. However, the number of activities purposely designed to foster students' explanatory abilities were low and not quite explicit (except in Christian's case).

5.3.1. Discussion

As I have shown throughout this dissertation, acquiring a certain degree of mastery in explaining natural phenomena is defended by many as a requirement for scientific literacy (Bybee *et al*., 2009; OECD, 2013; Ryder, 2001). The inclusion of this practice in science curricula rests on the belief that the search for explanations is one fundamental objective of scientists. My case-study teachers seem to be aware of the relevance that explanations have in science and science education; however, it is difficult to find examples in their enactment that can be categorised as purposive attempts to develop students' explanatory skills.

Some authors have noticed the absence of opportunities for students to systematically and effectively get engaged in the production of explanations in the science classroom. Zangori and Forbes (2013), for example, claim that the teaching and training of explanation building is highly underemphasised in real settings, especially in primary schools. Ruiz-Primo *et al.* (2010) also defend that teachers are not consistently supporting students in attaining proficiency in this disciplinary practice. Sadler (2006) notes that the same happens with argumentation: it is acknowledged as a central practice of the scientific community, but usually remains absent from typical science lessons. This lack of opportunities is detrimental to students' achievement of scientific literacy because, as stated in the *Next Generation Science Standards* (Council, 2013), "(s)tudents cannot comprehend scientific practices, nor fully appreciate the nature of scientific knowledge itself, without directly experiencing those practices for themselves" (p.xv).

The first step to ensure students' legitimate participation in science practices is to create learning environments in which they can *do* science and *discuss* about science. This includes having opportunities to gather and examine data within open investigations, share and debate ideas, and construct scientific explanations and arguments (Braaten & Windschitl, 2011). Katchevich, Hofstein and Mamlok-Naaman (2013) demonstrate that the quality of students' explanations in close/confirmatory lab activities is lower than those resulting from open-ended inquiries. Sandoval and Morrison (2003) go further and argue that if students articulate their own explanations for observed phenomena without explicitly attending to the epistemic discourse used during this practice, they may not "develop an informed understanding of what *doing science* involves" (p. 1276). This means that teachers should support students not just in the conceptual dimension of explanations, but also in its epistemic dimension.

Science studies recognise that to accomplish these goals –do science and discuss about science– the members of the scientific community use specific forms of talk which follow particular rules (Lederman & Abell, 2014); these forms of talk are referred to as registers, language games, or discursive practices (Driver *et al.*, 1994; McGinn & Roth, 2003). Usually, this normativity requires engaging in social processes of communicative interaction (Chang, 2011; Ruiz-Ortega *et al.* 2015). Ford and Wargo (2012) recognise that accepted forms of talk in classrooms usually come into conflict with norms of argumentation (Driver *et al*., 2000; Duschl & Osborne, 2002; Jiménez-Aleixandre *et al.,* 2000). Similarly, since explanations are social constructions (Sandoval, 2003), they demand complex dialogue interactions in which language is used according to certain norms that enable reasoning, sharing of ideas, and discussion (Lin *et al.,* 2017). As many authors show, though, this type of social interactions is not the most commonly promoted in traditional science classrooms (Lemke, 1990). Instead, we find a teacher-led classroom discourse, and a predominance of brief utterances by a few students with an emphasis on correct answers (Mortimer & Scott, 2003).

The latter is a fitting description of what I did observe in School-A. Adrian and Alba's communicative approaches and discursive moves (see §4.3.1.4, and §A.8.4) acted as guarantors of their epistemic authority in the classroom, something that notably limited students' willingness to share their ideas. In Adrian's case, this was reinforced by the way he presented and negotiated science learning: as a private practice (Stroupe, 2014). Like some of the teachers who took part in Stroupe's study, Adrian urged his students to complete the activities and tasks alone and silently –"*Everybody in silence and working, I do not want to hear a pin drop, please*" (Y9.O13-Ad)–, and gave them very few opportunities for collaborative learning. On some occasions, Adrian even made deliberate remarks about the individual nature of science learning –"*You have to do it alone. Work, read, summarise, and solve the tasks individually. Otherwise, you won't learn, no matter how well or bad I could explain it*" (Y11.O8-Ad).

Christodoulou and Osborne (2014) states that there is a reciprocity between the dynamics of the relationships established within the classroom and the way teachers talk with their students. This scheme, they affirm, may open, or hinder the creation of spaces for the co-construction of knowledge. That Adrian maintains a dominant position in terms of epistemic authority, and executes almost the totality of the classroom discourse, could help us understand why it is so difficult to find well-developed episodes of student-made scientific explanations in his lessons. Research on argumentation has corroborated that one of the reasons why science teachers rarely integrate argumentation into their instruction is that they find it challenging to lead and support the open dialogue interactions that this practice involves (Jiménez-Aleixandre *et al*., 2000; McNeill & Knight, 2013, Lin *et al.,* 2017).

On the other hand, Becca, Barney, and Christian designed environments and activities aimed at depicting science learning as a public and social enterprise. That is, in their lessons, teacher and students together became involved in the conceptual, epistemic, and social aspects of science practices, highlighting the cooperative –*"To introduce the topic, we will do a cooperative work activity in 10 minutes, and then we share it"* (Y11.O3-Be)– and dialogic –"(What) *I am most interested in is your act of sharing all that you have learned*" (Y9.O6-Ba)– nature of science learning. This seems to be the right pathway to favour the introduction of scientific explanations in the classroom, given that, as Moura and Guerra (2016) declare, "any pedagogic intervention aiming to discuss scientific practice should promote dialogue, thus changing classrooms into privileged spaces for debates about science and its practices" (p.755).

Numerous studies indicate that a change of these characteristics is more likely to be implemented and sustained if its underlying theoretical framework is compatible with teachers' conceptions and beliefs about teaching and learning science (Bendixen, 2002; Hand *et al.,* 2016; McNeill & Knight, 2013). Jones and Carter (2007) argue that teachers with constructivist epistemological orientations are more prone to use an inquiry-based instructional approach in their classes. Simon *et al.* (2006) particularise this idea for argumentation, agreeing that the implementation of argument-based inquiry strategies requires that teachers' views about science learning be compatible with constructivist principles. In the case at hand, it is curious that the two teachers who explicitly define themselves as constructivist (Adrian and Alba) are the ones whose students show the lowest levels of autonomy and ownership of learning (Jacobsen *et al.,* 2009) and who give the least importance to epistemic practices in the classroom.

An explanation for this apparent anomaly could be found in Tsai (2000). Following Lederman and Abd-El-Khalick's research (Abd-El-Khalick, Bell, & Lederman, 1998; Abd-El-khalick & Lederman, 2000; Lederman, 1999), Tsai highlights the potential relationship existing between teachers' beliefs about science and their beliefs of teaching and learning science. In his study, Tsai interviewed 37 Taiwanese science teachers, and found that 21 of them (generally, the most experienced ones) possessed what he called 'nested epistemologies'; namely, aligned systems of belief about science, teaching, and learning. Other teachers (including the most novice) presented multiple inconsistencies between their different systems of beliefs and their teaching practice. This might be connected to the widely-held perception that constructivist-based approaches may make teachers lose control over the classroom (Brooks & Brooks, 1999). After analysing both their interviews and their classroom behaviour (including the language used), I realised that Adrian and Alba's conceptions of knowledge seem to be more aligned with positivist views, according to which knowledge is objective and controlled by an authority figure (Huling, 2014). Teachers owning these perspectives tend to introduce teacher-centred didactic practices and activities focused on the transmission of factual knowledge (Abd-El-Khalick & Lederman, 2000), which is, indeed, what I found in the lessons of the school-A teachers.

Another agent that could be coming into play to understand these seeming inconsistencies is the context (Mansour, 2013; Millner *et al.,* 2012). Factors such as global and local policies, or school culture, may influence how beliefs are enacted in the classroom. So, while in many cases, there is consistency between teachers' beliefs systems and instructional practices, we must be cautious in taking beliefs as predictors for actions (Katsh-Singer, 2016).

5.4. Assertion #3: Teachers rarely display specific instructional sequences to promote the construction of scientific explanations. However, they use some strategies to interact and guide students in explanatory episodes.

Studies about science teachers' role in teaching epistemic practices suggest that they need to possess a range of appropriate instructional strategies to effectively steer students towards proficiency (Yilmaz *et al.*, 2017, Duschl & Osborne, 2002; Osborne *et al*., 2004; Zohar, 2007). Due to the relevance that scientific explanation has acquired in science education (NRC, 1996; 2012, Osborne *et al*., 2002), and to the acknowledged students' difficulties in constructing explanations (Hoffenberg, 2013; McCubbin, 1984), I found it reasonable to enquire about the specific strategies the participant teachers adopt to support this practice in Secondary science classes. My research question *Q1b* (Table 3.2) alludes to this.

In the previous chapter, I presented the results of the analysis conducted with each individual participant. This analysis was based on their modalities of classroom talk, the specific activities they proposed to help students understand how explanations are built, the discursive strategies employed to shape the process and to sustain students' efforts, and the most extended patterns of interaction in which teachers engaged during episodes of explanation production. Taking these results as a starting point, in this section, I compare the most prominent elements of teachers' Knowledge of Instructional Strategies (KIS), in searching for commonalities and differences.

5.4.1. KIS of the participant teachers

As with any other epistemic practice, the formulation of scientific explanations requires exposing students to the reasoning and discourses of the discipline, along with conscious participation in social interplays with the teacher and their peers (Beyer & Davis, 2008). In this teaching-learning process, classroom interaction models which include teachers' talk and other modes of communication occupy a central dimension for the analysis of the instructional strategies (Kaya *et al.*, 2016).

Mortimer and Scott (2003) refer to the ways in which teachers interact with the students to address the different ideas that emerge during episodes of knowledge construction as 'communicative approaches'. According to the analytical framework set forth by those two authors, communicative approaches comprise two dimensions that stem from the conversation between teachers and students (Figure 3.7.2.b). The first dimension splits into Dialogic and Authoritative approaches (depending on the diversity of perspectives considered during the episode). The second dimension distinguishes between Interactive and Non-interactive conversations (according to the level of student involvement). As detailed in §3.7.2, I used the four categories resulting from Mortimer and Scott's framework as coding categories to analyse how the sample teachers orchestrated their classroom talk when helping students to develop explanations.

The first thing to highlight from my results is that all the participants engage in more than one way to interact with their students. That is, the five teachers shift their communicative approaches from one explanatory episode to another. Mortimer and Scott (2003) recognise that this alternation between approaches is quite common, proposing that it reflects a variety of learning objectives. Thus, when teachers intend that students learn some canonical conceptual content, they usually adopt an authoritative approach; and when teachers want to encourage students' reasoning skills, they use a dialogic approach. The complex nature of scientific literacy –which entails mastery in various aspects of knowledge and practice (Burbules & Linn, 1991; DeBoer, 2000; Hodson, 1992)– may require such a variety of objectives. Scott (1997) affirms that "it seems reasonable to suggest that learning in the classroom will be enhanced through achieving some kind of balance between presenting information and allowing opportunities for exploration of ideas" (p.227), something about which he insists in Scott *et al.* (2006). The results of the study conducted by Furtak and Shavelson (2009) with four secondary science teachers in an American school support that an active, selective, and balanced combination of authoritative and dialogic approaches is the most beneficial for students' learning.

Table 5.4.1) Participants' communicative approaches.
**In some cases, the sum of the episodes under each category does not coincide with the total number of explanatory episodes; some episodes could not be classified according to the Mortimer and Scott's (2003) framework.*
***Some of the observed lessons from these participants were double lessons.*

Teacher	ADRIAN	BECCA	CHRISTIAN	BARNEY	ALBA
Total number of explanatory episodes/Lessons observed*	*27/52*	*19/32***	*16/28***	*16/22***	*15/17***
Interactive/Authoritative	22 eps.	5 eps.	4 eps.	7 eps.	11 eps.
Interactive/Dialogic	1 ep.	7 eps.	12 eps.	8 eps.	-----
Non-Interactive/Authoritative	2 eps.	3 eps.	-----	-----	3 eps.
Non-Interactive/Dialogic	1 ep.	-----	-----	-----	-----

As can be seen in Table 5.4.1, this balance is far from having been accomplished by the teachers in my study. In Adrian and Alba's cases (especially, in the former) there is a deep bias towards the Interactive/Authoritative communicative approach. In Section 4.3.1.3, I reported that Adrian sees the teacher as the presenter of a robust and accurate account of the scientific panorama. So, there are not many reasons why he should engage in dialogic interactions with his students when trying to explain something. Mortimer and Scott (2003) acknowledge that such transmissive views are still quite common. In Christian's case, the dominance leans towards the Interactive/Dialogic communicative approach, being common to find episodes in which Christian and his students explore together different perspectives to answer seeking-why questions. This is consistent with Christian's eminently social and collaborative conception of learning. Finally, in the cases of Becca and Barney, there is a somewhat more balanced distribution among communicative approaches (especially in the latter). It would be necessary to have many more (and longer) episodes to evaluate these trends more accurately, though[44].

Another noteworthy aspect is that, from the total of 93 episodes in which the different teachers engage to *explain* something, only one episode in Adrian's case can be classified as Non-interactive/Dialogic. The description provided by Mortimer and Scott (2003) for this category specifies that, in Non-interactive/Dialogic episodes, the teacher takes more than one perspective in consideration, but does not leave space for students' interventions. Before carrying out my analysis of the data, I thought the Non-interactive/Dialogic could be one common approach since, as the history of science has taught us, scientists often consider more than one explanation for a single phenomenon. If this were the case, it would be necessary to judge the potential explanations according to specific criteria to find the *loveliest* one (Barnes, 1995; Lipton, 2004). The result of my analysis coincides, however, with something that research extensively shows: when students are asked to produce scientific explanations, it is hardly expected that these will be challenged or evaluated against potential rivals (Driver *et al.,* 2000; Lemke, 1990).

Sampson and Blanchard (2012) propose that the lack of opportunities for students to evaluate alternative explanations may be related to the lack of opportunities with this practice that teachers themselves report having experienced during their own education and training stages. In light of these results, the instructional sequences used by Christian (§4.6.1.4) and Becca (§4.4.1.4) for guiding the production of explanations acquire greater relevance since, in both cases, the students must listen and evaluate various explanations. The main difference between these two participants' approaches is that, while Becca adapts a collaborative learning strategy that she applies in other contexts for an episode in explanation building, the strategy utilised by Christian seems deliberately designed for students to learn how to construct good explanations in science.

In Section 4.6.1.4, I described the instructional sequence that Christian employed in five of his 18 explanatory episodes (two in the pilot stage –§A.2– and three in the main study –E#4-Ch, E#7-Ch and E#10-Ch)–. Only in a few episodes in Becca (E#3-Be) and Barney's cases (E#7-Be; E#10-Ba) did I find a similar (albeit poorer) level of student's involvement to develop an explanation. The degree of students' autonomous engagement that Christian's teaching practice

[44] I am fully aware of the need to be cautious about the temptation of generalising the research results beyond the analysed cases. Each of the cases reported here is bounded as a period of teaching of certain lessons, covering only some curriculum topics, so it remains an open question how precisely the findings in my case study reflect the wider teaching, even for the participants.

involves requires more scaffolding and structured support than in the other cases. Perhaps this is one of the reasons why he has developed a specific teaching strategy to assist the students in the construction of explanations. Although it is not perfectly sequential, and it presents some variations, Christian's strategy can be structured in six stages (summarised in Figure 5.4.1.a.).

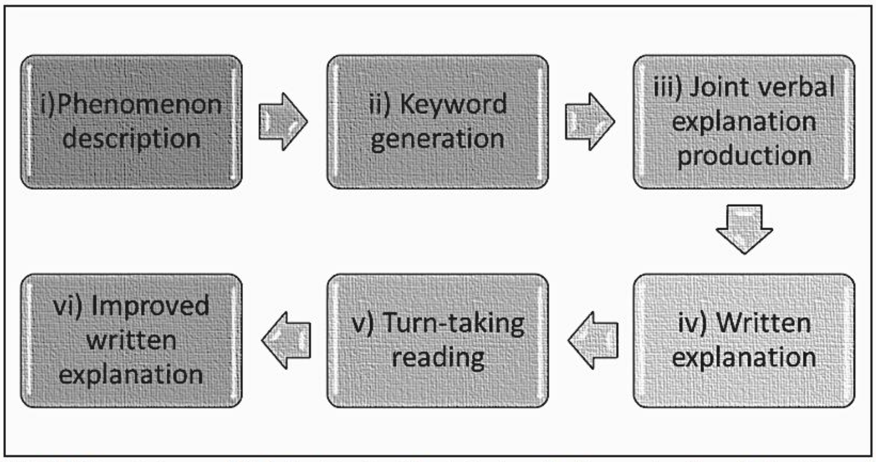

Figure 5.4.1.a) Different stages of Christian's instructional strategy for the construction of scientific explanation.

To start with, Christian introduces the phenomenon that the students must explain (Stage i). In all the observed episodes, Christian specifies that the final objective is indeed to build an explanation of it. After describing the phenomenon, he asks the students to think of some keywords (Stage ii). These keywords later communicated by individuals, or by dyads of students after a brief discussion. Once he has noted the keywords on the board, Christian commences the elaboration of the explanation, with the continuous involvement of the students through questions and comments (iii). That way, the whole class participates in the process of verbally constructing the explanation. The fourth step requires that each student writes their personal version of the jointly elaborated explanation (iv), for which they are given sufficient time. In the next step, students are paired up and take turns to read their respective explanations (v). Students must listen carefully to take some ideas that may be applied to their own explanation. This entails a process of self-evaluation. Sometimes, Christian choose some students to read their potential explanations aloud so that the whole class can comment on how to improve them. With their peer ideas in mind, students must develop an improved version of their explanations (vi).

In Becca's case, I could only observe the sequence presented in Figure 5.4.1.b in one of her explanatory episodes (E#3-Be). This sequence is based on a well-known cooperative learning strategy –the so-called '1-2-4'–. Therefore, it is not a practice-specific instructional strategy for building explanations, but an application of a more general technique. In Episode #3, Becca initiates the sequence by writing a statement about temperature and change of states on the whiteboard and asking the students to explain why that is the case (Stage i). They are given one minute to elaborate their own explanation (Stage ii), two minutes to share their personal explanations with a partner, discuss with her, and select the best one from the two proposals (iii), and then, four minutes to reach an agreed explanation as a group of three/four people (iv). The most interesting aspect of this episode is that students must evaluate alternative explanations and ascertain which one they consider the most convincing. After writing their consensual explanations on a post-it, reading them aloud and sticking them on the board (v), the students look for information on the Internet (with their i-Pads®), in order to decide which of the group-proposed explanations (if any) is the most satisfactory (vi).

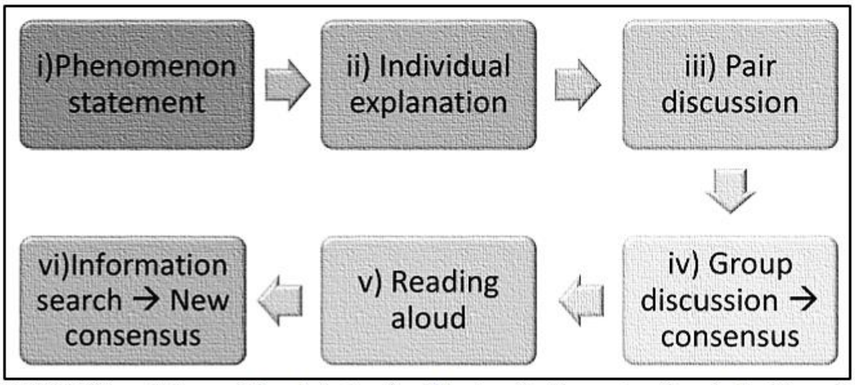

Figure 5.4.1.b) Different stages of Becca's instructional strategy for the construction of scientific explanation

In Christian's case, the direction of the elaboration process runs from the group to the individual (co-construction + individual refining), while in the case of Becca, it is just the opposite (individual construction + collective agreement). A further step in research on how to teach scientific explanation could be to work out which of these strategies is more effective in promoting students' explanatory skills (see §6.3).

The instructional sequence used by Becca in Episode #3 fits well with the first four phases of the Argument-driven inquiry instructional model (ADI) of Sampson, Grooms, and Walker (2011), while Christian's strategy includes five of the seven phases of which the ADI model consists (Figure 5.4.1.c). In both my participants' cases, though, instead of an argument, students must build a scientific explanation. The first step of the ADI model comprises the identification of the task by the teacher (Stage i), who should justify its rationale within the unit. The second step requires the generation of data (Stage ii). This should be done in collaborative groups. The next step involves the production of a tentative argument (iii). After this, the small groups must share their arguments with the rest of the class for these to be criticised, in order to decide which argument seems the most acceptable (iv). In the fifth stage, each student must elaborate on a written report for the whole experience (v), which will be blind reviewed by a peer (vi). Finally, each student will rewrite/improve their reports based on the reviewers' feedback (vii). The improved version of the argument is given to the teacher for assessment.

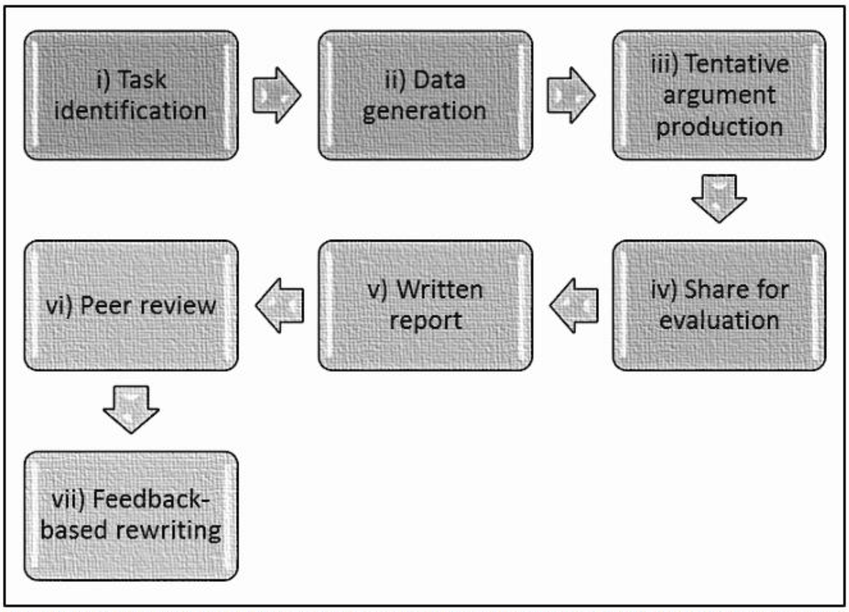

Figure 5.4.1.c) ADI instructional strategy for the construction of scientific arguments (adapted from Sampson* et al.*, 2011)

Sampson, Enderle, and Grooms (2013) revealed that not only content knowledge, but also students' scientific writing abilities and understanding of epistemic aspects of science were significantly improved thanks to the ADI model. Similarly, Songsil, Pongsophon, Boonsoong, and Clarke (2019) demonstrated that the students introduced to argumentation through their revised ADI instructional model (rADI) –which included modifications to make it more applicable to Thai educational contexts– outperformed the group that had been taught by a traditional inquiry and discussion-based approach to argumentation. These results might indicate that well-designed strategies such as those used by both Becca and Christian could help students to enhance their explanatory skills and to grasp some aspects of science-as-practice.

5.4.2. Discussion

Since Magnusson, Krajcik, and Borko presented their five-components model of PCK, Knowledge of Instructional Strategies (KIS) has been accepted as one of the key facets of this construct (see Figure 2.6). Magnusson and her collaborators divided KIS into three categories: i) Teacher's knowledge of subject-specific strategies to be used within a broad range of topics (e.g., guided inquiry); ii) Teacher's knowledge of topic-specific representations (namely, examples, analogies or models); and iii) Teacher's knowledge of topic-specific activities (experiments, simulations, and demonstrations, for instance). When the Pentagon Model was presented (Magnusson *et al.,* 1999; Park & Chen, 2012), these three subcategories of KIS referred only to knowledge about how to effectively teach science content. In the last decade, some authors have also explored teachers' Knowledge of Instructional Strategies for different disciplinary science practices. One of the most extensively studied has been scientific argumentation (Davis & Krajcik, 2005; Knight-Bardsley & McNeill, 2016; Osborne, 2014).

Literature on this epistemic practice illustrates a wide assortment of instructional strategies used by science teachers to promote argumentation in their classrooms; these rank from broad strategies –including: challenging students' ideas' weaknesses and/or inconsistencies (Mork, 2005), posing open-ended questions that raise a multiplicity of viewpoints and demand justification (Berland & Hammer, 2012; Berland & McNeill, 2010; Berland & Reiser, 2009; Jiménez-Aleixandre & Pereiro-Muñoz, 2005), questioning ideas in student-student discussions (McNeill & Knight, 2013; McNeill & Pimentel, 2010), and fostering critical discussions after conducting a practical (Ozdem *et al.,* 2013)– to specific strategies –including: pressing students to justify their claims with evidence (Simon *et al.,* 2006), modelling argumentation (McNeill, 2009; Yilmaz *et al.*, 2017), and proposing criteria for the construction and evaluation of arguments through prompts (Osborne *et al.,* 2004; Sampson & Clark, 2008; Sandoval & Reiser, 2004). These studies reflect the idea, embodied in the 'Taking Science to School' framework (Duschl *et al*., 2007), that "traditional instruction does not enable most children to attain a good understanding of scientific (…) practices, but there is evidence that (…) learning (…) could occur with appropriate instructional sequences" (p.219).

Although rare, we can find some researchers who have designed specific interventions to support learners in the production of scientific explanations. McNeill and collaborators (Lizotte *et al*., 2004; McNeill & Krajcik, 2006; McNeill & Krajcik, 2008) examine the use of different instructional practices –'defining scientific explanation', 'making the rationale of scientific explanation explicit', 'modelling scientific explanation', and 'connecting scientific explanation to everyday explanation'– during explanation-based lessons. These researchers conclude that specific instructional strategies play a fundamental role in students' understanding and use of scientific explanations, although all four were not equally effective in this purpose. For example, defining the different components of explanation and providing the rationale behind the framework used –in this case, the CER framework (see §2.5.4)– seem to have a positive impact on students' learning about argumentation, although it is not clear whether these two strategies can be independent (Lizzote *et al.,* 2004) or must be provided in conjunction (McNeill & Krajcik, 2006).

Of the practice-specific strategies for scientific explanation that McNeill and colleagues propose, only Christian applies one of them: 'modelling explanation'. Scholars show no agreement about the effectiveness of this instructional strategy, though. While some argue that students can learn what counts as a good explanation if they witness cases of acceptable and unacceptable exemplars (Saglam *et al.*, 2014; Osborne *et al*., 2004), others state that mere ostensive examples are insufficient for students to learn appropriate ways of explaining (McNeill & Krajcik, 2008; Solomon, 1986). The fact that modelling is, for Christian, only one stage within a broader sequence of instruction could contribute to increasing its effectiveness; this statement needs further research.

Something that the cited authors do not consider in their studies, but that has been shown to be essential for students' successful construction of scientific explanations, is the combination of both some domain-specific conceptual knowledge and a general structural reasoning knowledge of the practice. Sandoval (2003), for instance, proposes that students should be scaffolded into the general *epistemic game* (Collins & Ferguson, 1993) of scientific explanation with an integration of domain-specific science content; that is, students need to be explicitly taught "about what to explain in a particular problem with guidance about what a good scientific explanation looks like" (Sandoval, 2003, p.6). Kuhn, Schauble, and Garcia-Mila (1992) found that students' ability to interpret evidence and draw conclusions in an inquiry-based activity is constrained by their need to make sense of what is observed and to understand the scientific theories and/or principles behind the phenomenon.

Many other researchers in argumentation and explanation have noticed the importance of students having sound content knowledge when they need to transform data into evidence (Chinn & Brewer, 2001; Duschl *et al.,* 2007; Schauble, 1996) and for the reasoning stage (Metz, 2000; McNeill *et al.,* 2006; Zimmerman, 2000). Zangori and Forbes (2013) analyse the reasoning paths that elementary learners follow when building explanations. They conclude that these paths depend on students' domain-specific conceptual knowledge. When this knowledge is absent or poor, they almost exclusively manifest intuitive reasoning patterns. Every time that Christian uses the aforementioned instructional sequence for promoting students' explanatory accounts, he explicitly refers to the conceptual knowledge that underlies the phenomenon under explanation (e.g., through the keywords), which could facilitate the connection process. However, as previously stated, when students articulate scientific explanations about phenomena, what they construct is influenced both by their understanding of the science content and by their general understanding of the logic involved in scientific explanations[45] (Osborne *et al*., 2003). Stahl (2002) stresses this last point when he states that:

> "For (the science-as-practice) approach to be successful as a learning approach, students (…) need to ground their reasoning in more general disciplinary strategies, and connect the explanations or arguments they construct to more general disciplinary frameworks. For example, if students are learning about mass and density by designing toy boats to carry loads, they need to analyze and synthesize their results and work towards physical explanations, rather than focusing only on the goal of the boat-building task." (p.256).

Therefore, explicitly highlighting the generic structure of high-quality explanatory practices may promote student success in engaging in scientific explanations. In Christian's episodes, I could not find any evidence of this, nor in any of the other participants, which could call into question the effectiveness of the strategies used.

In addition to their reasoning patterns, disciplinary practices are characterised by the particular way in which language is put at the service of the final objective (Duschl *et al.,* 2007). Scientific explanations are social constructions (Sandoval, 2003), in such a way that the process of construction of an explanation can open a dialogical process (Mercer, 2000): "the act of explaining is dialogic because it involves picking up another person's utterance –the scientific idea– from its time, context, and purpose, and using it in one's own situation, to advance one's own feeling of understanding" (Ford & Wargo, 2012, p.371).

Dialogical processes –or epistemic dialogues (De Vries *et al.,* 2009)– require the reciprocal and reflective engagement of different participants (Burbules & Bruce, 2001) in the same discourse. Participants must, then, perform a series of discourse moves or communicative acts (Maybury, 1991), each with a singular epistemic function (Christodoulou & Osborne, 2014). Particularising for the elaboration of scientific explanations, we can say that only through these moves can an explanation become realised (Rocksén, 2016).

One of the biggest challenges I encountered during this research journey was to develop the coding scheme for analysing the discourse moves used by my participants in their explanatory episodes. The first source of difficulty was the enormous amount of data that I had collected for each teacher. A second source came from the fact that the participants spoke two

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[45] For an in-depth discussion about the structure of one of the most extended reasoning patterns put at stake when building scientific explanations –mechanistic reasoning– and some of the difficulties that students may encounter when trying to apply it, go to §A.1.3.

different languages[46], which added complexity to my already heterogeneous data. But perhaps the main obstacle was the shortage of examples of academic works about the communicative acts that teachers execute to promote different epistemic practices in the classroom.

Some authors claim for the need of this line of research (Harris *et al.,* 2012). In the field of teacher education, for example, Christodoulou and Osborne (2014) demands that "science teacher educators need to identify ways in which future science teachers can be helped to develop their discursive repertoires to ensure that they are presenting the full range of epistemic practices to students in a systematic and consistent manner" (p. 1296). In this regard, D'Souza's doctoral dissertation is highly relevant.

D'Souza (2017) explores the influence that distinct types of discursive moves may have on the development or inhibition of argumentative practices in Chemistry lessons. Starting from the idea that participating in a discourse means assuming a particular identity within a community of practice (Wenger, 1993), and under both the Inquiry-Oriented Discursive Moves framework (Whitacre & Nickerson, 2009), and the Toulmin's Argumentation Pattern framework (Toulmin, 1958), D'Souza devises a coding scheme for communicative acts performed in argumentation-driven lessons. Her scheme contains 16 items, clustered in four categories: Re-voicing, Questioning/Requesting, Telling, and Managing.

To elaborate my own coding scheme, I took as starting points the SEDA framework for the analysis of classroom dialogue (Hennessy *et al*., 2016), Kaartinen and Kumpulainen's analytical tool for social interactions (2002), and the Tutor Dialogue Move Coding Scheme (Lehman *et al.*, 2012). From these three frameworks, I developed a coding scheme with 115 items, grouped into seven clusters: Initiating, Continuing, Extending, Referring Back, Replying, Commenting/Reinforcing, and Concluding moves. Almost all the codes proposed by D'Souza did also appear in the analysis I conducted with my participants. Although this cannot be considered as proof of the validity of my analytical proposal, it can contribute to generating some confidence in it. Furthermore, the fact that many of the discourse moves I present and code in this work had already been used by other teachers in completely different contexts, opens the doors to naturalistic generalisation (Stake, 1995; for further details on this concept, see §6.4).

In addition to discursive moves, the participants' diverse communicative approaches came into practice through concrete patterns of interaction (Scott *et al.,* 2006). There is only one interaction pattern that was repeated across the participants: the triadic IRF sequence (see Table 5.4.2). Some studies imply that IRF sequences may not be the best structure to use in

[46] One of which, moreover, is not my mother tongue.

contexts in which students are expected to learn to construct their own explanations (Barnes, 2008; Duschl & Osborne, 2002; Cazden, 2001; Gutierrez, 1993). However, several authors argue that the third move of this pattern –namely, the teachers' feedback act– does not always need to be a conclusive evaluation, but that it can be used for other purposes. Wells (1999), for example, suggests that, in some contexts, "[this] third move functions much more as an opportunity to extend the student's answer, to draw out its significance, or to make connections with other parts of the students' total experience during the unit" (p.200). That is; when triadic sequences are adopted to "clarify, exemplify, expand, explain, or justify a student's response; or to request the student to do any of these things" (Skidmore & Murakami, 2016, p.102), it results in discursive interactions that may foster students' understanding and explanatory reasoning.

Table 5.4.2) Summary of patterns of interaction present in each participant' case.

PATTERN OF INTERACTION	ADRIAN	BECCA	CHRISTIAN	ALBA	BARNEY
IRF sequences	✓	✓		✓	✓
IRE(F)P complex sequences			✓		
Student interventions sequences		✓	✓		✓
Student-student interaction			✓		✓
Student's intervention without being addressed			✓		
Teacher's question – Teacher's answer			✓	✓	
Student's question – teacher's answer			✓	✓	
Hesitations and pauses	✓		✓	✓	
Alternation with interruptions			✓		
Interruption		✓			
Out loud reading			✓		
Group sharing			✓		

Christian is the participant whose interaction patterns showed the greatest level of complexity. In Table 4.6.1.4.e, I presented the multiplicity of forms adopted by the triadic sequences of interaction in Christian's episodes. On the other hand, Christian is the teacher whose conceptualisation and implementation of the scientific explanation in the classroom are closest to the operational definition developed for this thesis. This result seems to suggest that what is relevant to promote this practice is not so much the interactive framework chosen, but the purposive use of the third movement.

5.5. Assertion #4: Teachers do not possess specific assessment models for the construction of explanations.

In 1993, Novak claimed that "(e)very educational event has a learner, a teacher, a subject matter, and a social environment. I would like to suggest a fifth element: evaluation" (p. 54). Today, nobody doubts that evaluation –including assessment– is an intrinsic part of any teaching-learning experience, and that teachers need to know a wide repertoire of assessment strategies (Toplis, 2015).

Magnusson *et al.* (1999) included Knowledge of Assessment (KAs) as one of the fundamental components of their Pentagon model of PCK (§2.6). The KAs component was divided into two different categories. The first category refers to teachers' knowledge of the learning aspects that *would be relevant* to assess. But also, to teachers' understanding of the learning aspects that *can actually be* assessed. The second category within KAs refers to teachers' knowledge about the different methods, instruments, approaches, activities, tools, strategies and procedures by which certain learning aspects may be assessed, both for informal and formal approaches. This second category also refers to teachers' understanding of the advantages and limitations of each method and instrument, along with their appropriateness for the learning dimension being assessed (Magnusson *et al*., 1999). For example, students' conceptual understanding may be adequately assessed through paper-based tests, whereas their ability for scientific inquiry might require assessment through practical examination or laboratory reports (Orion *et al*., 1997). The purposes of my research are aligned with methods that might be suitable to assess students' engagement on epistemic practices, such as performance-based assessments (Duschl & Gitomer, 1991).

During decades, research about assessment at different education levels has shown that teachers over-rely on content-based tests that merely evaluate students' conceptual understanding (Doran *et al.,* 1994; Magnusson *et al.,* 1999) –the 'learning science' component of scientific literacy (Hodson, 1992). The pioneering studies in this area did not specify whether this predominance of content-embedded tests was due to a lack of awareness of the need to assess other dimensions of scientific literacy –learning *about* science and learning *to do* science (Hodson, 1992)– the result of a lack of knowledge of other and more effective methods and instruments, or if there are other reasons. More recent studies indicate that science teachers find it difficult to know how to assess learning aspects that go beyond content acquisition, like students' understanding of the Nature of Science (Hanuscin *et al.*, 2011) and their ability to participate in argumentation practices (Simon *et al.*, 2006; Knight-Bardsley & McNeill, 2016); this may contribute to these literacy dimensions being left in the background (Wang & Buck, 2016). I decided to analyse my participant teachers' KAs of scientific explanation to see whether teachers also encounter difficulties when assessing this practice.

In Chapter 4, I report the results of my observations and my interviews with three of the five participant teachers. For each of them, I analysed their Knowledge of Assessment (KAs) concerning the production of scientific explanations in the classroom (research question Q1c, §3.2). Although each participant has a very particular way of understanding the role of assessment in the teaching-learning process and opts for different methods to assess different learning dimensions, we can find some common patterns across the teachers with respect to the assessment of explanation-building. These commonalities are the ones I present in this section. I begin by summarising the most relevant aspects related to the KAs of each teacher, and then I proceed to discuss them to put them into perspective within the academic literature.

5.5.1. KAs of the participant teachers

Once each case teacher's Knowledge of Assessment had been analysed (Chapter 4, plus §A.8.4, and §A.9.5), their common points can be summarised in the following three statements:

i) In their science lessons, all the participants deploy a wide range of instruments, methods, and activities to assess different learning dimensions.

Adrian, following the guidelines from the science department of School-A, assesses students' conceptual understanding and mathematical skills by way of memory-based and numerical calculation written tests. He also assesses students' performance in experimental activities from oral presentations and lab reports. Finally, he assesses students' involvement in the daily classroom activities through classwork, homework, and voluntary participation in tasks checking and assessment. Alba's assessment regime is very similar. Both Alba and Adrian claim that they would like to assess other relevant aspects of learning, like students' progress and students' effort, respectively, but they doubt that the right circumstances exist for this.

Becca and Barney consider that there are so many learning dimensions to assess that no single tool or method could cover them all. Combining this belief with their creative and innovative character, the result is that these two teachers use a huge variety of activities (homework, classwork, lab work and online work), approaches (self-assessment, peer assessment, teacher assessment) and many formal and informal tools (teacher-created tests, student-created tests, quizzes, reports, oral presentations, student-made videos, canvas, infographics, letters, murals) to assess students' content understanding and other skills, as well as their attitude towards work, their behaviour and their capacity for self-improvement. A meta-instrument of assessment that they prioritise in their classes is the rubric. Becca and Barney use rubrics common to all teachers at School-B, and also design their own rubrics for specific activities and projects. They always detail in advance to their students what they are going to assess. Rubrics give Becca and Barney the opportunity to assess different aspects within the same task or activity. Both agree that this is possible thanks to the incorporation of tablets in the classroom.

Finally, Christian also assesses different aspects of his students' learning, especially those competences related to engagement in science practices. This translates into a wide variety of instruments and assessment methods, which include multiple-choice tests, mock exams, posters, group work, homework, hands-on activities, science projects, worksheets and explanation-writing, from a formal approach; and observation, prediction-telling, student self-evaluation, questioning, the plenary grid, classroom discussions, computer games, quizzes (with Kahoot®) and skills checklists, from an informal one.

ii) In four of the five participant teachers' cases, it was not possible to find any evidence of the possession and/or use of any specific model, strategy, or instrument to formally assess students' ideas, abilities, and engagement in scientific explanation production. In Christian's case, the possession of some type of informal model for the assessment of the explanations elaborated by the students may be intuited, although is not explicitly shown.

Among the teachers who do not formally assess students-made explanations, we find two different attitudes. On the one hand, we have Adrian and Alba, who openly acknowledge that, although important, for them it is not a priority and explicit objective that students become competent in this epistemic practice. They do not propose or plan any activity (individual or collective) aimed at fostering students' proficiency to produce an explanation of a given phenomenon. Nor do they ever ask students to develop written explanations. In her interview, Alba mentioned that students, especially the oldest ones, only seem to show interest in a task if this is formally assessed. She is aware, then, that her lack of evaluation of students' explanations could lead them to perceive that this as a non-relevant practice, and not take much interest in it (§A.8.5). Furthermore, it can be said that Adrian and Alba do not conceive teaching science-as-practice, so they do not generate opportunities in the classroom for students to get engaged in authentic science practices. Research on teachers' knowledge of assessment (Gearhart & Osmundson, 2009; Pareja, 2014) has determined that this knowledge is closely aligned with the curricular goals and with the instructional strategies implemented. Therefore, it is not surprising that I could not find a single example of formal explanation assessment in the classes of teachers from School-A.

Somewhat different are the cases of Becca and Barney. These two teachers do introduce different aspects of science learning that go beyond the acquisition of conceptual knowledge in their lessons. Becca, for example, during my time with her, went to the school laboratory every Thursday so that students could work on their inquiry projects, and she emphasised on some epistemic aspects. Barney did something similar every Tuesday out in the vegetable garden (§A.9.3). Besides, in both cases, I could find examples of instruments used to assess student's competence in other practices, such as experimental design and graph interpretation. On the other hand, Becca and Barney recognise that for them it is fundamental that their students know how to compose explanations. But, and in this they coincide with Alba and Adrian, it is not an objective that they develop explicitly in their classes. Considering this, one might come to understand that they do not possess any formal model to assess either the process of elaborating the explanation nor the product. It should be clarified, however, that in some of the episodes analysed for Barney and Becca, there are some aspects related to the explanations that are formally assessed. But these are peripheral aspects that have to do with students' communicative skills, their ability to answer teachers' question or to work as a team, not with the development of their ability to explain a phenomenon using science.

Finally, we have the case of Christian. As seen in the previous chapter, his lessons have a clear practice-based orientation. Besides, on several occasions, this participant proposes to his students an activity consisting of building an explanation for an observed phenomenon. To help them in this task, Christian has even developed a specific sequence of instruction, which includes a section to improve the quality of the explanations built (see Figure 4.6.1.4). All this could suggest that, although not formally structured, he has some sort of mental model of what a high-quality explanation is. Except for a few verbal hints –"*If you want to explain it really well, then include those* [key] *words*" (E#4-Ch)– there is no clear evidence of what this model consists of, so it is difficult to say what specific aspects of the practice of constructing explanations are the ones that Christian formally assesses. Sometimes, Christian asks his students to write their explanations in their notebooks, so that he can assess them later. In these situations, stating more clearly what he expects from their explanations might help the students engage in the practice more effectively.

iii) In the observed episodes of scientific explanation production, some kind of informal assessment on students' performance takes place.

Although, as we have just seen, most participants do not assess either the product or the process of explanation crafting, I found episodes in every case in which scientific explanations are present in one way or another. In these episodes, teachers use many and varied informal strategies to help students in the task of producing –or, more frequently, understanding– the explanation. Thus, all of them pose questions, utter some comments, and make observations aimed to gauge and/or monitor whether the students are following the reasoning process and assimilating the information provided. In some episodes, the teacher corrects a reasoning error, as Adrian does with a tautology in episode #24 and with the labelling in Episode #26 (§4.3.1.4). There are others, like Becca in episode #3, who opts not to provide any evaluative comments to the students' answer, and then seeks a consensual explanation among all. How each teacher acts depends on the specific goal of the activity or task in which the explanation takes place.

To all that has been said, it should be added that most of the supporting comments and questions that teachers make during an explanatory episode are aimed to guide students towards a canonical explanation. That is, except Christian's, these comments and questions have the purpose of reinforcing some conceptual understanding, for which the explanation is instrumental, but not that the learners enhance their abilities to construct scientific explanations.

We can summarise the participants' KAs by saying that they all present various methods, instruments, and activities to assess different aspects of their students' learning. These aspects include –only in some cases, and to a different degree– the assessment of students' proficiency in certain science practices (especially those related to the design and performance of experiments). This shows that teachers are aware that there are many assessable dimensions in science learning and that a single instrument can rarely capture them all. However, only in one of my cases could I find evidence of some kind of formal assessment for the elaboration of explanations, although in a very vague way.

5.5.2. Discussion

According to Osborne and Dillon (2008), in any teaching-learning experience, three dimensions must be considered: curriculum, pedagogy, and assessment. Translating this statement to the practice of building explanations, we can say that there are some questions that must be answered: what is a scientific explanation, and what should we teach about it?

What pedagogical strategies should be used to promote the learning of this practice? And, finally, how should students be assessed? This last question about assessment involves more questions that need to be answered, including i) What should be assessed: the product or the process? ii) What models, strategies, instruments, and approaches could be utilised for assessing students? iii) Could a learning progression of this practice be defined in order to know when a student can be considered proficient? The results of my research, of an eminently exploratory character, can serve as a starting point for reflection on these issues. I believe this reflection is essential, because in the academic literature, teachers' conceptions and strategies for assessing non-conceptual learning aspects such as epistemic practices have received minimal attention (Gotwals & Songer, 2013; Yao & Guo, 2018).

As I have summarised in the previous section, the most noticeable result of my research about KAs with five high school teachers in three different schools from two different countries is that none of them makes explicit mention, at any time, of any specific skills or content to assess concerning the production of explanations. One might wonder if this result is surprising. If we attend to the results of other research studies on Knowledge of Assessment, the answer would be 'no'. We have seen that, for most of the participants, that their students acquire the ability to proficiently engage in explanatory practices is not an explicit curricular goal. Some authors have enquired into the relationship between teachers' views on assessment and their educational objectives, concluding that there is an alignment between them. For example, Duffee and Aikenhead (1992) examined the assessment methods of six science teachers addressing a STS-based curriculum. They found that, while the teachers showed a variety of assessment techniques, their choices were clearly aligned to their goals of instruction and their beliefs about science. In a more recent study, Park and Chen (2012) analyse the connexion between PCK components' for four teachers from the same high school working in the topics of photosynthesis and heredity. Their analysis through PCK Maps (§6.2) reveals that Knowledge of Assessment is minimally incorporated into teachers' PCK for these topics. In those cases in which KAs was present, it was moderately connected with Knowledge of Instructional Strategies, which in turn was connected to teachers' Orientation Towards Science.

Further research that sought to establish relationships between teachers' PCK components shows results that differ from the above mentioned. In their study with three teachers who voluntarily implemented an argument-based enquiry approach in their lessons, Suh and Park (2017) found that Knowledge of Assessment (KAs) was seldom associated with other PCK components, a result similar to Aydin *et al*. (2015). The explanation that Suh and Park venture for such disconnection seems very promising. They suggest that they could not recognise evidence of teachers' KAs in their interviews and observations because the participants mostly used implicit informal formative assessment, but rarely introduced formal assessment for argumentation. Kelly and Licona (2018) concede that teachers' assessment criteria for epistemic practices tend to remain tacit and unrecognisable for the students.

This situation is very similar to the one that I encountered in my own study. In almost all the episodes of explanation building, the teachers utilise some strategies to engage students in the elaboration process, to a greater or lesser extent. In Becca's case, for example, an episode takes place in which she raises an activity whose purpose is to find a consensus explanation for a phenomenon (E#3-Be). Although Becca uses some ongoing informative assessment methods, such as questioning, it was not possible to identify evidence of formal and summative assessment in her performance. Something similar was found in all the other participants, even in Christian's case. Christian does ask his students to write explanations that he may later assess. But neither in front of the students, nor in our interview, does he specify what elements of the practice he will consider or what instrument he will use to assess them.

Another aspect that should be noticed is that, at the time of my observations in School-A, both Adrian and Alba had less than five years of classroom experience. Based on the results presented in Chapter 4, we can conclude that they are the two participants with less developed KAs of epistemic practices in general, and of scientific explanation in particular. The construction of explanations as an assessable activity is completely absent from their evaluation systems. As they recognise, their summative assessment instruments are limited to content-based tests, lab work, and classwork, where only participation and outcomes are valued. But in none of these situations, is the ability of students to explain phenomena assessed. Alba mentions in her interview that she would like to assess more dimensions other than students' conceptual understanding, but that the lack of time, the high number of students, and her insufficient training in this respect make it not possible (§A.8.1). Adrian also admits that he would like to introduce a more practical approach in his classes, which could lead to a change in the way he assesses.

The situation we find in Alba and Adrian is not unique. Researchers accept that inexperienced teachers usually possess little and vague knowledge about methods and instruments of assessment (Pareja, 2014). Other authors have reported a discrepancy between the assessment methods that teachers would like to use according to their conception of teaching and learning, and those that they eventually end up using. For instance, Bol and Strage (1996) find a misalignment between ten biology teachers' self-ascribed higher-order instructional goals and the type of items encountered on their tests, which primarily assessed memorisation. More recently, Kaya (2009) conducted a mix-methods study with 216 pre-service teachers in two Turkish universities, with the purpose of analysing the relationship between their PCK's components for the topic of 'Ozone layer depletion'. In their interviews, more than one-half of the participants mentioned non-traditional approaches to assessment, such as portfolios; however, the statistical analysis showed that most of them did not successfully connect this type of assessment with their teaching. In both Adrian and Alba's cases, this dichotomy is appreciated.

One of the proposals that have been made to try to align instructional goals and assessment in science classrooms is the creation of learning progressions (Duncan, 2009; Duschl *et al*., 2007). According to Duschl (2019), the notion of 'learning progressions' was driven by the idea, defended by researchers and educators, that the learning of science should be sequenced over long periods of time. This idea, in turn, was motivated by the shift in the conceptualisation of science learning from a mere acquisition of factual knowledge –the 'science-as-knowledge' model– to a genuine engagement in epistemic practices (Berland & McNeill, 2010).

Learning progressions are defined by Corcoran, Mosher, and Rogat (2009) as "empirically-grounded and testable hypotheses about how students' *understanding of, and ability to use*, core scientific concepts and *explanations and related scientific practices* grow and become more sophisticated over time, with appropriate instruction" (p.15; emphasis added). Learning progressions are based on learning theories, research about Pedagogical Content Knowledge in the topic/practice of interest, and research about the associated disciplinary knowledge (Duschl *et al.,* 2011). Notwithstanding this theoretical basis, the development of learning progressions necessarily rests on empirical examination (Duschl *et al.*, 2011; Krajcik *et al.*, 2012; Yao & Guo, 2018). That is, they must respond to an analysis of authentic students' performances, not the logic of the practice (Monteira & Jiménez-Aleixandre, 2019).

With the increasing emphasis on the need to enculture students into the practices of the scientific communities (Jiménez-Aleixandre & Erduran, 2007; Beyer & Davis, 2008; Berland & Reiser, 2009), there has been a resurgence of interest in the pathways that learners follow to achieve mastery in these practices (Osborne *et al*., 2016). There are some elucidating examples of non-topic-based learning progressions in the literature. For instance, Schwarz *et al.* (2009) propose a learning progression of scientific modelling organised around two dimensions – 'models as tools for predicting and explaining', and 'models change as understanding improves'. After piloting their learning progression, Schwarz and her collaborators found that both elementary and middle school students were able to construct, evaluate, compare and revise scientific models. However, the authors recognise that they do not have evidences about the utility of their learning progression in the long-term. Sevian and Talanquer (2014) also select two dimensions –assumptions and modes of reasoning– to develop a learning progression of chemical thinking (CTLP). Moon *et al.* (2016) use the CTLP as an analytical tool to examine students' engagement in argumentation and formulation of causal explanations in two different classes of Physical Chemistry. They conclude that students use primarily relational reasoning, and rarely include causal mechanisms in their explanations.

Berland and McNeill (2010) describe a learning progression for scientific argumentation that might help develop didactic sequences to promote student engagement in this practice. The learning progression considers three dimensions: instructional context (which depends on the degree of openness of the tasks and the level of scaffolding), argumentative product, and argumentative process. Berland and McNeill adapt their learning progression to lessons on different topics at different educational levels. They provide evidence to conclude that, with adequate support, 10-11 years-old students are able to properly engage in argumentative practices, and that this ability develops in complexity over time.

Osborne *et al.* (2016) consider that Berland and McNeill's work is not methodologically sound. It that study, they critique, students' proficiency in scientific argumentation is assessed through a qualitative-based analysis which is not systematic; that is, students' competence in each category as defined by the levels of their learning progression is not adequately measured. Osborne and collaborators propose and validate their own learning progression. This is based on Toulmin's model of argumentation (Toulmin, 1958), and consists of three levels of increasing sophistication that differ in the cognitive load required to establish connections between claims and pieces of evidence. To boost validity, Osborne and colleagues followed a cycle of development and refinement that included data from think-aloud interviews, pilot tests and large-scale administrated tests, with students aged between 11 and 14. After applying the final version of their learning progression, they conclude that middle school students are capable of identifying and making claims, selecting evidence to support a claim, and even providing reasoning that links claim and evidence. They also recognise differences between students' reasoning ability in scientific contexts and general contexts.

Songer, Gotwals, and their team have made some remarkable efforts to develop a learning progression of scientific explanation (Gotwals & Songer, 2013; Songer & Gotwals, 2012; Songer, Kelcey, & Gotwals, 2009). Taking Toulmin's framework as the theoretical basis for their works, these authors develop a seven-phase learning progression for the construction of explanations. In each phase, the level of scaffolding provided by the teacher for each of the components of the Claim-Evidence-Reasoning model (§2.5.4) is considered. In Figure 5.5.2.a, the learning progression proposed by Gotwals and Songer in these papers is summarised.

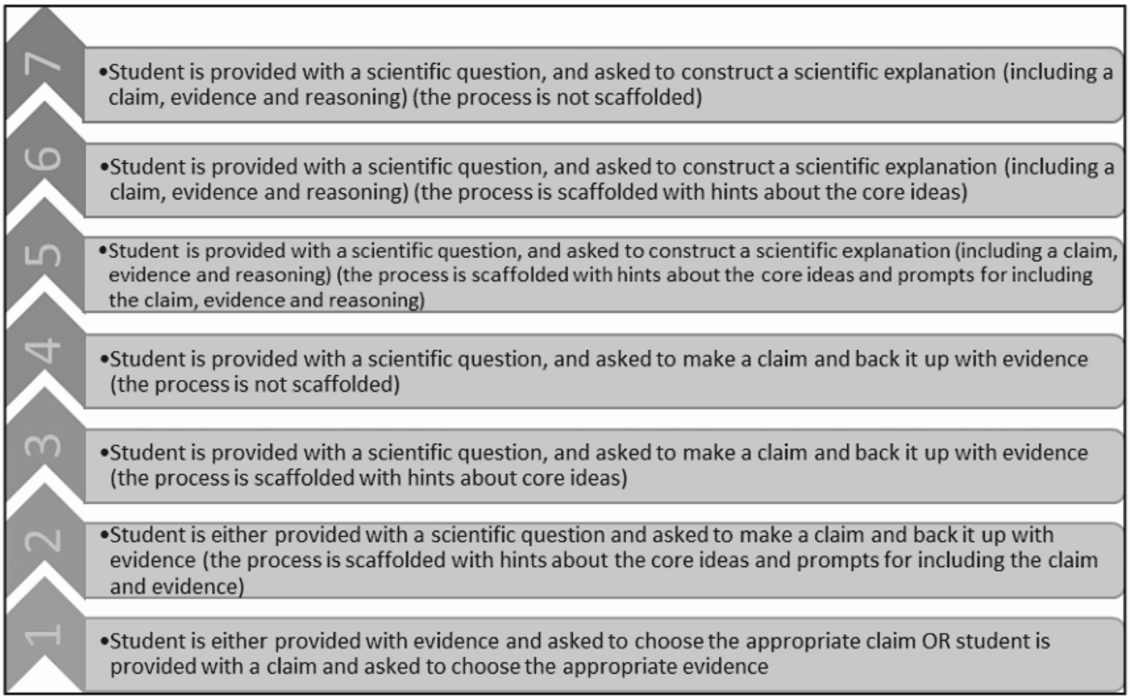

Figure 5.5.a) Learning progression in evidence-based explanations (adapted from Gotwals & Songer, 2013)

Gotwals and Songer's learning progression presents, in my view, a core problem, which is the choice of the Toulmin's model (1958) as a framework to define the basic elements that an explanation must possess. Under this framework, what the learning progression evaluates is the ability of students to construct arguments, so I do not see that it brings anything new with respect to the other mentioned proposals. Given that we engage in explaining and in arguing for different epistemic reasons (Osborne & Patterson, 2011), that these two practices are characterised by distinct linguistic structures (Tang, 2016), and that the criteria to evaluate the quality of an explanation differs from those to assess the quality of arguments (Brigandt, 2016), it seems reasonable to conclude that a learning progression of scientific explanation should adopt a different framework as its basis. This is, indeed, what Yao and Guo (2018) aim to do.

Yao and his team believe that it is necessary to continue working towards a more widely developed learning progression of scientific explanation to have a broader and deeper comprehension of how to promote students' progress in this practice (Yao & Guo, 2018). Guided by this belief, they design a learning progression of scientific explanation that not only clarifies the key components for explanations from a different framework, but also delineate the levels for each component.

In Figure 5.5.2.b, I present the two different levels of proficiency that Yao and Guo define for each of the four components of the PTDR model (§2.5.4), the basic level and the in-depth level. Combining the two levels for each element, these scholars develop a learning progression for the construction of explanations. This progression consists of phases of increasing complexity, ranging from the mere identification of the phenomenon (which would be a description, without explanatory value) to the elaboration of an explanation in which all the elements are present and these are joined by a process of complex reasoning.

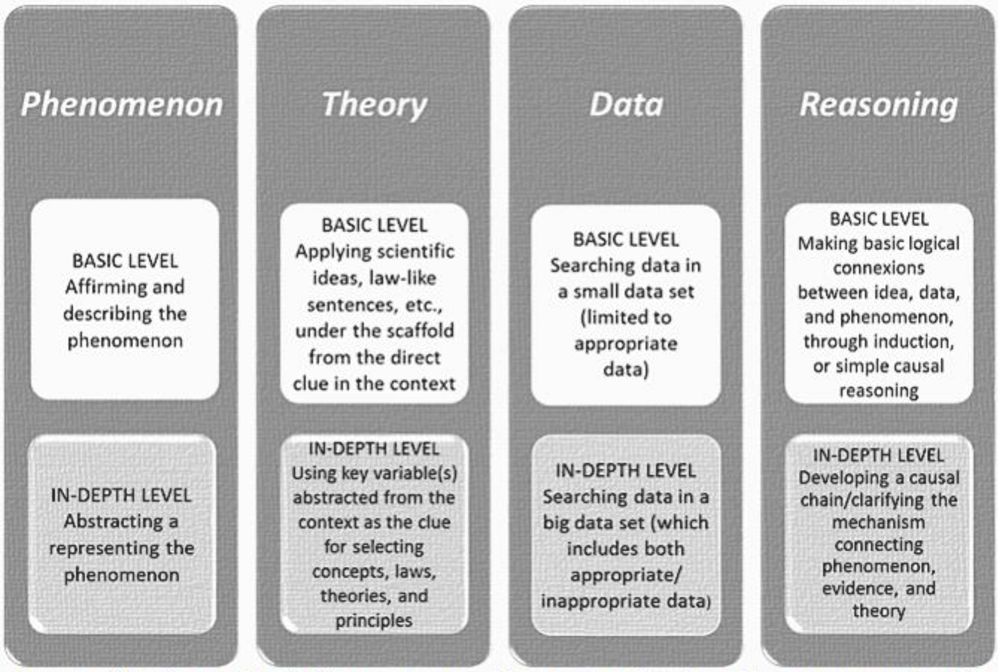

Figure 5.5.b) Proficiency level of the components of the PTDR model (adapted from **Yao & Guo, (2018)*).***

One of the constraining elements that Alba mentioned in her interview is the low level of competence that students show when they must participate in the production of scientific explanations (§A.8.3). Other authors agree that the acquisition of a certain level of proficiency in such complex practices as the elaboration of explanations is indeed challenging for students (Gotwals & Songer, 2013; Songer & Gotwals, 2012). As such, it requires explicit instruction on multiple fronts over a long time (Duschl *et al.*, 2007). This instruction must be continuous, sequential, coherent (Gotwals & Songer, 2013; Schneider, 2015), and adapted to learners' real abilities (Monteira & Jiménez-Aleixandre, 2019).

> "To develop a thorough understanding of scientific explanations of the world, students need sustained opportunities to work with and develop the underlying ideas and to appreciate those ideas' interconnections over a period of years rather than weeks or months. This sense of development has been

> conceptualized in the idea of learning progressions". *The Next Generation Science Standards* (Council, 2013, p.2).

Attending to these demands, it would be useful to implement in the classroom the PTDR learning progression (or some other candidate) to support teachers in the process of guiding students in scientific explanation crafting. This may facilitate the design of instructional sequences; however, it also presents some challenges regarding assessment.

Scholars declare a certain degree of reciprocity between learning progression and assessment. On the one hand, there must be some procedures and instruments to measure and assess what students know and what they can do at each of the defined levels of the learning progression (Gotwals & Songer, 2013). Only in this way could we trace how they progress over time (Corcoran *et al*., 2009). But on the other hand, learning progressions offer explicit and validated models of cognition that can act as a framework for the design of meaningful assessment (Berland & McNeill, 2010; Wilson, 2004). For instance, Osborne *et al.* (2016) propose a way in which their learning progression for argumentation could be adapted for formative or summative assessment purposes. There is evidence in the literature that indicates that the alignment of assessment systems with a learning progression framework can provide more information about a larger range of students (Songer *et al.*, 2009; Songer & Gotwals, 2012; Gotwals & Songer, 2013).

The pertinent question, then, is how to assess the different aspects that define a learning progression for scientific explanation. One of the objectives of my study was to analyse the models, instruments and activities used by teachers to assess this practice in their classrooms (research question *Q1c*). Wang and Buck (2016) place this same research objective in the context of dialogic argumentation. They investigate a single physics teacher to try to elucidate his PCK of argumentation. The main findings concerning the participant's KAs are two: i) he found it hard to guarantee the fairness in the assessment process; and ii) he regretted the lack of a formal rubric for argumentation assessment. Wang and Buck agree that the assessment of argumentation is a difficult task for which the design of a reliable and applicable rubric could be of great help.

My view is that the construction of scientific explanations is not a simple activity that can be easily measured; rather, it is a complex practice that requires a deep understanding of content knowledge, mastery on some procedural knowledge and reasoning abilities, and the possession of mature epistemic knowledge. As such, assessing students' explanations might be a difficult task for science teachers[47]. We have seen that my participant teachers barely assess any aspect related to students' production of explanation. Unfortunately, with the data that I have it is not possible to assure if they do not assess this practice because the find it to be a difficult task, if they do not do it because they lack rubrics for it, because they do not know which method or instrument would be the best for each assessable aspect, or simply because they do not think it is important enough, despite what they affirm in their interviews. Although my findings are limited, I think my study offers good reasons to believe that research on teachers' KAs of scientific explanation is a field in which much remains to be done. Improving the range and quality of assessment items aligned with learning progressions that might be used both to diagnose and assess student understanding and performance of scientific explanation building should be a priority for future research and development.

5.6. Assertion #5: Teachers consider some inhibitors and some fostering conditions for designing environments in which explanation-production plays a significant role

As stated in Assertion #2 (§5.3), the production of explanations is far from being a priority practice in my participants' science lessons. In that section, I echoed some authors who strive to justify such position, although many of the studies cited were about argumentation and not about explanation. In those studies, it is suggested that for these types of practices to occur, learning environments must allow the deliberate and balanced introduction of conceptual, epistemic, and social goals (Duschl, 2008). This, in turn, entails the creation of opportunities for learners to experience first-hand the ways of reasoning and discourse of each disciplinary practice.

In this section, the justification of why it is so difficult to find episodes of explanation construction is provided by the participants themselves. As I commented when introducing my research questions (§3.2), in their interviews, some teachers indicated some elements that they perceived as obstacles to implement the formulation of explanations in their classrooms. They also mentioned some characteristics they saw as facilitators for such implementation. This was not included on my interview schedules but emerged during our conversations. Given that mine is an exploratory and interpretive study, I was genuinely interested in knowing the perspective

[47] This complexity is also present in the case of argumentation. However, the well-known CER framework (§2.5.4) is used by teachers as a guide for the assessment of students' performance in argumentation (Wang & Buck, 2016). This suggests that science teachers could benefit from the possession of a similar model to assess the production of explanations in the science classroom. In Appendix A.1, I try to justify why I consider Yao and colleagues' PTDR model (Yao *et al.*, 2016) to have all the necessary features to take on this role.

of the people involved in it, so I opened a new line of investigation following the interest shown. Below, the conceptions of my participants are presented. I also discuss and compare my findings with the barriers and enablers to explanation-based approaches identified on previous studies.

5.6.1. Participants' perceived constraining and fostering elements for the introduction of explanatory practices

In our interview, Adrian admits he would like to include more students-led explanatory activities in his lessons (§4.3.1.1). However, the Spanish public education system does not provide him with the means this would require, in his opinion. These means –which he does not specify– would open the doors to a more student-centred approach to learning, he thinks. Adrian also noted that the large class sizes (with more than 30 students in some of his groups) restrain the introduction of activities that require deep thinking engagement from students. Adrian said that technological devices (like laptops or tablets) could facilitate this task, although he did not clarify how and why.

I asked Alba whether she considers it significant to foster students' capacity to produce explanations of natural phenomena. She responded affirmatively, but spontaneously added that students' lack the necessary language and reasoning skills to construct coherent explanations (§A.8.3). Alba also thinks that the range of the syllabus (along with its disconnection with students' interests) makes it difficult to introduce in the class learning elements that differ from content knowledge. Alba is aware that focusing on science practices like explanation crafting requires a change in her teaching approach, for students to become more actively engage in the tasks and activities, and her role not to be limited to content delivery. She said that there are too many students per classroom for this to be a real possibility. Besides, Alba believes her scientific education and teaching training did not provide her with the necessary resources to accomplish this approach in her lessons. Alba adds she would need higher support from the other staff members and more group cohesion for this change to be effective. A final obstacle refers to assessment. Alba recognises that neither she nor the other members of the science department formally assesses students' attempts to construct explanations. She admits that this might impede students from seeing this practice as relevant, since they tend to value more what has a direct influence on their final qualifications (§A.8.3). In the single-case study conducted by Wang and Buck (2016), the Physics participant teacher also suggested that his students would not accept the relevance of argumentation in science unless their performances in this practice were formally assessed.

There are a couple of external impediments that Barney believes may hinder the creation of opportunities for learners to elaborate explanations about phenomena (§A.9.1). One is the pressure that education inspectors and some parents exert to cover the entire syllabus, which Barney finds excessively long (and, like Alba, irrelevant for students, in some cases). That is, even though Barney values other aspects of science learning, he admits that he must focus on the acquisition of conceptual knowledge. Moreover, the high number of students per class obstructs the introduction of those practices that require extra time for reflection and discussion, and that need to be performed thoroughly and consciously, like explaining phenomena.

Despite the aforementioned difficulties, Barney decided to lead our interview towards those aspects of his workplace that may favour the inclusion of discursive and discipline-based epistemic practices in the science classroom (§A.9.1). The first thing Barney highlights is the support that the leadership team (and the rest of the faculty members) places in each teacher. This support is based on trust, respect, and affection. Consequently, School-B teachers have a high level of freedom and autonomy to introduce as many changes and novelties as they deem appropriate; this leads to innovative practices which are in harmony with teachers' epistemic and pedagogical beliefs. Moreover, Barney says, it is the management team who encourages teachers to introduce continuous innovations. Barney claims he has always felt supported by the other staff members, and that no one has ever questioned the effectiveness of his proposals and his teaching approach (which is built around the application of the scientific method, within which he places, as a final stage, the construction of explanations). This has helped Barney acquire the necessary confidence to defend his different educative projects –like the vegetable garden– to the students' parents.

5.6.2. Discussion.

As some of my participants did for scientific explanation, numerous authors have distinguished several constraints to implementing argumentation in the classroom, including limited instructional time (Sadler 2006), ineffective teacher training (Richmond *et al*., 2016), teachers' consideration of students' abilities (Sampson & Blanchard, 2012), insufficient rubrics for argumentation assessment (Wang & Buck, 2016), teacher's predominant epistemic authority (Wang & Buck, 2016), teachers not believing that argumentation may help students improve their content knowledge (Zohar & Nemet, 2002), teachers not viewing argumentation as an educational goal in itself (Beyer & Davis, 2008), and teachers lacking PCK of argumentation (Simon *et al.*, 2006; McNeill & Knight, 2013).

The relevant aspect here is that we are not *necessarily* dealing with *real* constraints. But the fact teachers conceive them as such, is enough justification for neglecting epistemic practices like scientific explanations as fundamental educational goals. Although it is beyond the scope of this study, it would be interesting to analyse whether the lack of means and resources referred to by Adrian and Alba is really an element that does prevent the introduction of explanation-building activities in the classroom. In this regard, the work of Ramnarain, Nampota, and Schuster (2016), which reveals the influence of the context on teachers' pedagogical orientation towards inquiry-based activities, is illuminating. These authors found that teachers at disadvantaged schools usually embrace didactic and teacher-centre forms of instruction, while teachers from privileged schools are more prone to adopting inquiry-based approaches. A varied assortment of contextual factors –including learners' ability, availability of resources, class size, time constraints, school culture and parents' expectations (Ramnarain & Schuster, 2014) may influence such difference in teaching orientation. Many of these factors are reported by Adrian and Alba. Although School-A is not classified as 'disadvantaged', there is an appreciable difference between the average income level of the inhabitants of the city in which this school is located (§4.3), and that of the families that attend Schools B (§4.4.) and C (§4.6), which are both independent schools. This could explain, at least, in part, why in Adrian and Alba's classes it was so difficult to find episodes of student-made explanations. Grandy and Duschl (2007) might also be considered to understand the low presence of practice-based orientations in School-A, since they state that "(t)he institutional culture of public education is severely constrained by economical, ideological and pedagogical conditions. Such constraints have the effect of promoting certain forms of curriculum, instruction, and assessment practices while denying others" (p.158).

The reasons that both Adrian and Alba cite to justify the practically null relevance that explanation construction does have in their lessons can be qualified as 'external'. Fernández-Balboa and Stiehl (1995) would refer to them as 'contextual barriers.' One of the conclusions of the work conducted by Beyer and Davis (2008) with an elementary teacher is that the barriers that most shaped the role of scientific explanations in her practice were belief-related; that is, 'internal'. First, the participant did not consider that building explanations could help students acquire or strengthen their content knowledge (which was her priority). A second barrier is that she did not deem this scientific practice as a fundamental educational goal in itself, but rather as a pedagogical strategy for helping students improve their experimental skills. These attitudes and beliefs limited the opportunities the participant provided for students to develop their understandings and skills concerning the practice of explaining phenomena. Neither Adrian nor

Alba recognised that promoting explanatory competence is not an objective they have (although Adrian did admit this later in our interview). The only internal barrier acknowledged by my participants is Alba's beliefs about students' communicative and reasoning limitations (§A.8.3). Sampson and Blanchard (2012) also note that the introduction of argumentative activities may be hindered by teachers' beliefs about students' low abilities.

On the other hand, practically all the elements that Barney mentions as facilitators for the creation of an environment favourable to scientific explanations coincide with the agents that Höttecke and Silva (2011) consider necessary for mediating in any innovative change. Höttecke and Silva –whose analysis focuses on how to foster a History and Philosophy of science-oriented teaching and learning– mention i) the support and intellectual stimulation of school leadership teams to innovative proposals; ii) explicit administrative support (concerning documents, curricula, and regulations needed to ease the implementation); iii) support and collaborative work from all teachers, to adapt ideas and materials to each specific context; and iv) support from different experts for the developments and adaptation of ideas and materials. Other researchers have drawn attention to the role of organisational factors in the implementation of any innovative educational approach, showing that teachers are more likely to promote and sustain change when there are multiple levels of support within the system (Bol *et al.*, 1998; Coburn, 2003; Suh & Park, 2017).

As discussed in Section 5.3.1., external support is not usually enough, though. All the facilitating conditions cited by Barney –autonomy, peer and leaders' support, and propensity to innovations– when taken together, may create affordances that make the change towards productive engagement in explanation building more likely to occur. However, they cannot guarantee it will indeed occur. Even under the ideal conditions of administrative and school leadership support, there is a wide variation in the quality of a practice-based approach, specifically at the implementation level (Suh & Park, 2017). Teacher knowledge and beliefs are contributing factors to the sustainability of a new practice that we must take into consideration.

Interestingly, the teachers who least include the practice of explanations in their classrooms (Adrian and Alba) were those who tried to identify impediments to this introduction. Barney, the most thoughtful and critical with his own work, mentions both facilitating elements and hindering elements. Finally, neither Becca nor Christian (the two participants in which the most significant episodes of explanation-building happened) referred to fostering condition or to potential barriers for the implementation of scientific explanation at any point. All the enablers and obstacles for the design and implementation of explanation-based activities that were mentioned by my participant teachers in their interviews are summarised in Table 5.6.1.

Hindering conditions	Fostering conditions
· Perception of students' abilities · Curriculum demands · Students' ratios · Time constraints · Lack of support and group cohesion · Lack of proper training · Lack of assessment methods · Lack of means and resources (technological) · External pressure	· Support from the management team and the teaching staff · Autonomy · Willingness to introduce innovations

Table 5.6.1) Hindering and fostering conditions perceived by the participants for designing explanation-driven learning environments.

CHAPTER 6. CONCLUSIONS, LIMITATIONS, AND RECOMMENDATIONS FOR FURTHER RESEARCH

6.1. Overview

This dissertation gives an account of the results of the investigation I have conducted during the last three years. Since this project was conceived, my focal interest was to explore and understand what secondary school teachers do to foster and evaluate the formulation of scientific explanations in the classroom, and to relate this to their knowledge and beliefs about the role of explanation as a core epistemic practice in science. Using the PCK Pentagon Model (Park & Chen, 2012; Magnusson *et al.,* 1999) as a conceptual and analytical framework, my interest crystallised into one guiding question –(Q1) *What is teachers' Pedagogical Content Knowledge of scientific explanation?*– which was broken down into three sub-questions –(Q1a) *What ideas, knowledge and beliefs do teachers hold about scientific explanation?*; (Q1b) *What instructional practices do science teachers engage in during science lessons to support students in constructing scientific explanations?*; and (Q1c) *How do teachers assess students' attempts to construct explanations?* (see §3.2). To these, a fourth research question was added during the course of my inquiries –(Q2) *What do teachers perceive to be the fostering and/or hindering conditions for the teaching of scientific explanation construction in the classroom?*

Academic literature endorses that PCK is a complex construct, composed of individual but interconnected elements (Abell, 2008; Park & Chen, 2012; Magnusson *et al.*, 1999). The study of such a complex and highly context-sensitive phenomenon pointed to the case study approach as the most suitable research methodology. This type of study demanded an in-depth understanding of teachers' beliefs, meanings, ideas, and actions about scientific explanation. Given the virtual absence of examples with this focus, my case study needed to be exploratory and descriptive in nature, and interpretive and qualitative in terms of analysis. It, therefore, belongs to ERP2 (Taber, 2013).

Five schools were contacted to be part of this project; ultimately, only a group of teachers from three of these schools completed the data-gathering stage. The five concluding participants –Adrian, Becca, and Christian, together with Barney and Alba– worked in markedly different schools in two different countries –Spain and England– and presented a notable variety in levels of teaching expertise in their respective science disciplines.

As detailed in Chapter 3 (§3.6), data were collected from a multiplicity of sources to create a strong description of each teacher's PCK and teaching practice, and to improve the trustworthiness of the study. Classroom observations, semi-structured interviews, and fieldwork notes (as well as some informal conversations) were my sources of information. The analysis of the data thus collected occurred in multiple steps (§3.7). First, individual data were coded and categorised within the three different domains of PCK of my interest (namely, Orientations Towards Science, Knowledge of Instructional Strategies, and Knowledge of Assessment). The results of this within-case analysis are reported in Chapter 4. The second round of analysis was conducted through cross-comparisons, which resulted in the emergence of five assertions presented and discussed in Chapter 5.

Chapter 6 is the final chapter of this dissertation. This chapter provides a series of implications that the findings of this study on PCK of scientific explanation might have for researchers, teachers, and educators. Before these implications are elaborated, a summary of the main findings is presented, followed by a discussion of some limitations concerning the methodology and the methods chosen.

6.2. Summary of Research Findings

Based on the case profiles provided in Chapter 4, some commonalities in the participants' teaching approaches and beliefs on scientific explanation were highlighted following a PCK framework, and expressed in the form of assertions (Chapter 5). The five assertions made can be seen as potential answers to my research questions (see Table 3.7.3). In the next sections, I summarise these answers.

6.2.1. Q1a. What ideas, knowledge and beliefs do teachers hold about scientific explanation?

In Magnusson, Krajcik, and Borko (1999), the PCK component 'Orientations Towards Science' (OTS) was described as the general ways of conceptualising science teaching. Those authors unfolded the definition provided by Grossman (1990), according to which OTS comprises science teachers' knowledge about how students learn and what they should learn at different ages. Friedrichsen, Van Driel, and Abell (2011) later expanded this definition to also include teachers' knowledge and beliefs about the Nature of Science.

Research on teachers' OTS has been active for more than three decades (Gess-Newsome, 2015); throughout that time, the number of studies that have focused on PCK of scientific practices has remained low (Osborne, 2014; McNeill e*t al.*, 2016). However, as Davis and Krajcik (2005) claim, it is essential to analyse PCK of disciplinary practices as a distinctive aspect of PCK. Particularising for the case at hand, it is imperative to have information about teachers' knowledge of the role that explanation plays in both science and science education, and their knowledge about how to construct high-quality scientific explanations. This was the aim towards which my first research sub-question (Q1a) pointed.

Most contemporary scholars and educators readily assent that the ultimate goal of scientists is to elaborate explanations (van Fraassen, 1980; Taber, 2007). The wide acceptance of this idea could lead us to think that scientific explanation is not a topic that requires in-depth discussion or analysis; nothing further from reality. For more than half a century, questions such as the distinctive nature of scientific explanation, its structure and criteria of quality, have been debated *ad nauseum* from multiple perspectives and fields, connecting with some of the most basic discussions of science itself: "[s]cientific explanation constitutes the alpha, as regards the objectives of science, and the omega, as for a conceptualisation that integrates and brings into play all the other conceptualisations" (Estany, 1993, p.229)[48].

According to the science education community, teachers should aim for their students to acquire a certain level of proficiency in scientific literacy (Osborne, 1998; Berland & Reiser, 2009; NRC, 2012; OECD, 2013) in terms of conceptual knowledge, thinking and discursive skills, and knowledge about what science consists of (Hodson, 1992). Given that an improvement in learners' ability to build scientific explanations can help them develop and strengthen their conceptual understanding of science (Driver *et al.*, 2000; McNeill & Krajcik, 2006), their practical and discursive skills (Beyer & Davis, 2008; Aydeniz & Ozdilek, 2015), their epistemological beliefs (Kuhn *et al.,* 2006), and can contribute to increasing the value students give to science (Lombardi & Oblinger, 2007), scientific explanation should occupy an eminent position within what is taught in the classroom (Beyer & Davis, 2008; McNeill & Krajcik, 2006; Osborne, 2007). This, in turn, would require that teachers –who are responsible for the planning, delivering, and assessment of science lessons– have the possibility to experience and reflect on this epistemic practice.

Based on my reading and subsequent analysis of papers and books on explanation, before commencing my fieldwork, I had developed an operational definition of 'scientific explanation' (see §2.5.4). According to it, a scientific explanation is *an account based on the articulation of some theoretical knowledge and the interpretation of some empirical facts, which is constructed through a process of reasoning with the objective of making sense of a certain phenomenon.* This characterisation had a dual purpose. On the one hand, it was intended to summarise some of the consensus reached by scholars after decades of intellectual battle

[48] The original is in Spanish. The translation has been made by the author of this thesis.

(§2.5.2). On the other, it was intended to illustrate the specific practice to which numerous education policy documents and science curricula around the world refer (§2.5.1).

Taking this operational definition as a starting point, one of the first findings of my research was that, on the vast majority of occasions on which the teachers used the word 'explain' or posed a why-question, they did not do so with the meaning that I had proposed. In Table 5.2.c, I gathered all the different meanings for 'explanation' displayed by the participants during the observed lessons. These were divided into scientific and non-scientific explanations, and categorised according to their object, objective, and explanatory relationship (§5.2.1). As was shown in Table 5.2.b, the most widely demanded –and provided– types of scientific explanation in my participants' classes were i) causal and mechanistic explanations. This result coincides with that reported by Osborne and Patterson (2011), who relate it to the micro-macro connection that appears in science curricula; and ii) anthropomorphic explanations. Given the pedagogical character that many authors attribute to this form of explanation (Zohar & Ginossar, 1998; Treagust & Harrison, 2000; Helldén, 2005), it is not surprising that its use is so widespread across the teachers in my study.

Among non-scientific meanings of the word 'explain', the most widely used is, by far, 'justification'. Considering that citing the reasons why something is believed to be the case is a colloquial meaning of the term, it is expected that it slips right into the classroom. However, as Scriven (1962) warned more than half a century ago, it is important not to confuse the facts that justify an answer to a why-question with the answer itself. Being aware that these are two different practices (with different purposes and different epistemic rules) could assist teachers in understanding what curriculum developers and scholars mean when say that they should foster the construction of explanations in the classroom. Which, in turn, would facilitate the design of effective instructional strategies and materials.

The aforementioned coexisting meanings were differently introduced by the participants in their lessons. Thus, when they requested an explanation or posed a seeking-why question to their students, they did not always refer to the same thing, and did not expect the same type of answer. None of the teachers made the slightest allusion to this polysemy at any time, neither during the interviews nor during their classes.

When asked directly about their conceptualisation of the verb 'explain', all the participants referred to a singular meaning, although most were not able to provide a well-specified answer. In the cases of Becca and Alba, moreover, the meaning they alluded to in their interviews did not coincide with any of the meanings they performed in the classroom. This shows the notorious tension that usually exists between what teachers admit to thinking and believing (narrated PCK) and what they eventually put into practice (performed PCK) (Daehler *et al.,* 2015).

Some studies submit that how science is conceived by practitioners may have a profound impact on their learning objectives (Hodson, 1986). The participants of my case study characterise science in very different ways. While for Adrian, science is a body of knowledge, and for Becca, a source of answers, both Alba and Barney understand science as a particular way or method to apprehend reality. Intending to make their responses more specific, I asked the sample teachers for their views about scientists' objectives. Almost everyone pointed to explanation as the ultimate goal. Thus, Becca said that scientists "*observ(e) everything and try to explain why*" (I-Be). Christian affirmed that "*what science fundamentally seeks is to explain natural phenomena*" (I-Ch). Alba claimed that scientists *"try to explain why things happen*" (I-Al). And Barney acknowledged that "*building explanations is an aspiration of scientists*" (I-Ba). Adrian did not mention explanation production as one of the objectives of scientists, just saying that they dedicate to "*conduct experiments"* to *"draw conclusions"* (I-Ad).

Appreciating such consistency in their answers about the relevance that the explanation of phenomena has for scientists, I wondered if one of the educational targets of my participants would be, indeed, that their students become proficient in this practice. Although each teacher produced a fairly extensive list of objectives (Tables 4.3.1.2.a, 4.4.1.2.a, 4.6.1.2.a, A.8.2.a, and A.9.6), none of them mentioned mastery in producing explanations as a priority. Becca and Christian said that they strive to promote students' reasoning skills, which is, according to the PTDR model (§2.5.4), a necessary element to construct scientific explanations. However, they did not note this association.

Orientation Towards Science is believed to act like a filter through which teachers view and interpret any aspect of teaching and learning (Kagan, 1992). The low level of priority that my participants gave to achieving expertise in explaining phenomena could help us understand i) why they prompt so few opportunities for students to engage in the production of explanations; and ii) why in most of the episodes I observed in which the teachers asked/provided an explanation (except a few in Christian and Becca's classes), this task was a means and not an end in itself. Quite often, the purpose behind the process of explaining was to introduce and deepen content knowledge. In some recorded episodes from Becca and Christian, the elaboration of an explanation was used to strengthen students' thinking and practical abilities.

In summary, although teachers recognise explanation-production –as has been operationalised for this research– as an essential scientific practice, they find difficulties in defining it, they do not see it as a priority learning objective, and, hence, they seldom purposely implement it in their lessons.

6.2.2. Q1b. In what instructional practices do science teachers engage during science lessons to support students in constructing scientific explanations?

One of the underlying assumptions of this thesis is that communities of scientists engage in an assortment of disciplinary practices that, taken together, constitute a situated way of knowing (Meyer & Crawford, 2011). Out of the total types of scientific practices, I have focused on the so-called 'epistemic practices.' Epistemic practices are a set of mental and physical actions, defined according to a series of agreed rules, that lead to the creation and/or development of knowledge (Chang, 2011).

Conceptualising science as a set of practices has profound implications for the way science is taught (Christodoulou & Osborne, 2014; Stroupe, 2015). In addition to presenting conceptual content, science teachers must design instructional strategies to help students engage in different epistemic practices and to effectively support and drive them towards proficiency. To do so, teachers need a particular form of knowledge, which Magnusson, Krajcik, and Borko (1990) identified as Knowledge of Instructional Strategies (KIS). Magnusson and colleagues divided KIS into two subcategories: Knowledge of Language Devices –both interactional and academic (D'Souza, 2017)– and Knowledge of Activities. I analysed my participants' KIS following their division.

The elaboration of scientific explanations is an example of discipline-based epistemic practice (Duschl, 2019). Scientific explanation has become a central focus of interest among researchers and educators all over the world (OECD, 2013; Bybee *et al.,* 2009; Ryder, 2001). Given that it is very unlikely that students "learn how to reason and explain in a scientifically acceptable manner by simply telling them what to do" instead of making them "participate in a community in which such practices [a]re experienced, developed and practised" (McRobbie & Thomas, 2000, p.211), teachers must know what specific strategies they can apply to create such conditions.

There are some studies devoted to analysing the strategies exercised by teachers to teach how to produce scientific explanations (e.g., Lizotte *et al.,* 2004; McNeill & Krajcik, 2008). However, these studies are scarce and do not provide much detail about how these strategies can be brought to life in educational settings. As other authors have done for argumentation

(Yilmaz *et al*., 2017, D'Souza, 2017), I examined in-depth the specific instructional moves that the participant teachers performed to promote and sustain the elaboration of explanations in their classrooms.

Epistemic practices are discursive activities (De Vries *et al.,* 2002). That is, they consist of communicative moves or interactions aimed at promoting the production and improvement of knowledge and understanding (Christodoulou & Osborne, 2014). These interactions must take place in a social and cultural context that is meaningful for the community of participants (Young, 2009). All the member of this community must then share some paradigmatic background assumptions (Tuomela, 1980). Particularising for the case at hand, we can say that only through these moves can a scientific explanation become realised in a science classroom (Rocksén, 2016).

To characterise the KIS that teachers enacted to guide students during the process of building an explanation, I analysed their modalities of communicative approach, the discursive moves they employed to shape the process, and the patterns of interaction in which they engaged during these episodes. I also presented the activities within which the explanation construction occurred, as a means to contextualise the language devices.

As stated in Section 3.7.2, I used Mortimer and Scott's framework (2003) to analyse how the participants interacted with their students to address the ideas that emerged in the course of an explanatory episode. According to this framework, teachers can get involved in four distinctive varieties of 'communicative approaches', namely, Interactive/Authoritative, Interactive/Dialogic, Non-interactive/Authoritative, and Non-interactive/Dialogic. As shown in Table 5.4.1, all the sample teachers engaged in at least two forms of communicative approaches, the Interactive/Authoritative and the Interactive/Dialogic being the most widely used.

Considering that specific approaches are more suitable for some learning objectives than others, it is not unusual to find such combinations and alternations of approaches among science teachers (Mortimer & Scott, 2003). However, since the construction of an explanation is an epistemic dialogue (De Vries *et al.,* 2009; Mercer, 2000; Ford & Wargo, 2012), a greater proportion of the Interactive/Dialogic approach should be expected in these episodes. This is clearly the case for Christian and, to a lesser extent, for Becca and Barney. This coheres with the dialogical, interactional, and collaborative nature of these three participants' teaching practice. At the other extreme, we find the cases of Adrian and Alba, in whose explanatory episodes, the presence of a Dialogic approach is occasional, being swallowed up by the Interactive/ Authoritative approach. This result is not unexpected either, since these two teachers (who happened to be the least experienced) have a teaching style strongly based on the transmission of a single perspective of knowledge.

The participants' communicative approaches came into practice through concrete patterns of interaction and discursive moves (Scott *et al.,* 2006). The interaction pattern most widely used was the IRF structure (Table 5.4.2), albeit in varied forms and with different levels of complexity. Some scholars advise that the triadic structure does not favour classroom dialogue, since it does not open opportunities for students to present and reason about their own ideas (Duschl & Osborne, 2002; Cazden, 2001; Gutierrez, 1993). This could lead us to infer that this type of interaction pattern is not the most appropriate in an environment where the production of scientific explanations is intended to be stimulated. However, other authors argue that the third move –that is, the feedback provided by the teacher– can be used in such a way that results in discursive interactions that promote students' explanatory reasoning (Skidmore & Murakami, 2016; Well, 1999). Some of the communicative acts coded as 'Extending moves' (see Table A.3.4) were used by the participants to expand the explanation-building process by bringing new perspectives into the dialogue. For instance, in Episode #11, after evaluating a student's answer, Becca gives specific instructions for her to construct a mechanistic explanation, thus opening new avenues of reasoning (E#11; Y10.O3-Be). This suggests that the focus should be placed not so much on the patterns of interaction as on the concrete moves that take place within them.

Discourse moves were characterised by Carletta *et al*. (1997) as "the building blocks for a conversational structure" (p.22). My participants used a great diversity of such moves to influence the process of explanation during the episodes I observed. As a result of my analysis of these moves, a 115-items coding scheme was devised (§A.3.4), organised around seven categories –Initiating, Continuing, Extending, Referring Back, Commenting/Reinforcing, Replying, and Concluding moves (adapted from Kaartinen & Kumpulainen, 2002).

Although each participant uses the communicative acts that best suit their teaching style and learning objectives, they all show some consistency in the way these are applied. Explanatory episodes usually start with an explicit Initiating move, being this a direct instruction, an invitation, or a (set of) question(s) to contextualise the problem. The function of the Initiating move is to draw students' attention toward a phenomenon that needs to be explained. The opening interaction leads to a series of conversational turns shaped by a battery of related questions, requests, or comments to encourage students' participation. This second set of moves may have two different purposes: i) they are designed for the students to elaborate their own or their peers' ideas and reasoning; or ii) they are aimed at bringing into the discourse different perspectives to expand or redirect the explanation. The first group refers to what I coded as ‘Continuing moves.’ The second, to ‘Extending moves.’ I found 32 different acts that teachers performed to prompt students to develop prior contributions (e.g., asking for justification or inviting elaboration), and 15 ways to introduce new perspectives (sometimes, those of other students, but, more often, the teacher/canonical view of the phenomenon). Referring acts were fundamental to help the students make sense of the discourse they were building (e.g., by connecting the explanation with their reality). Commenting/Reinforcing moves contributed to motivate students and instil some confidence in them as explainers. And Replying moves strengthened the dialogic character of the process of construction of the explanation, giving more prominence to the students and getting them more actively involved. Finally, the participant teachers displayed 32 Concluding moves to close the explanatory episodes. Some sounded quite definitive (e.g., summaries), but others left the interpretation of the phenomenon open to further contributions.

As for the activities in which the explanatory episodes are framed, it is worth noting their oral character. There are only a couple of occasions when Christian asks his students to write an explanation. The other are joint constructions in which the entire class is involved through discussion, questions, and dialogue. Thus, there is a strong interactive component in explanatory activities, either teacher-student (all the participants) or student-student (only in Becca and Christian’s lessons). In these activities, the teacher acts as a guide and/or leader, helping the students to build the explanations through the aforementioned discursive moves.

More relevant for my research interests is the purpose with which the activities were proposed. In the vast majority of the observed episodes, the articulation of the explanation is not the final goal, but a means, an accessorial tool, part of an activity targeted at achieving other curricular objectives (e.g., promoting conceptual understanding). However, among Beca and Christian’s lessons, I found some episodes in which the construction of the explanation *was* the activity itself. Namely, these teachers proposed some tasks conducting to the elaboration of an explanation for a given phenomenon (e.g., E#3-Be; E#4-Ch).

It is in the last sort of episodes where the specific instructional sequences used by Christian (§4.6.1.4) and Becca (§4.4.1.4) make an appearance. Christian’s sequence can be outlined with the following steps: Phenomenon presentation and description–Keywords gathering–Co-construction process–Individual construction (writing)–Sharing and evaluation–Individual improvement. Becca, for her part, includes the following stages: Phenomenon presentation–Individual explanation–Pair discussion–Group discussion + agreement searching –Sharing and evaluation–Information search + new agreement searching. The episodes in which these sequences appear are long; they take a whole lesson or even two. In them, the teachers explicitly say that they expect that students make use of the scientific knowledge they possess to build a good explanation for a phenomenon. The teachers lead the learners through the process, but much of the responsibility for recalling and articulating knowledge rests with the students themselves.

Unlike those reported in Lizotte *et al.* (2004) or McNeill & Krajcik (2008), Christian and Becca's instructional sequences do not make any explicit reference to the elements of a scientific explanation or its quality criteria. Nor do they seem to be (at least in Becca's case) exclusively designed for explanatory purposes. That is, they belong to the most Basic level among instructional strategies (Yilmaz *et al.*, 2017). Notwithstanding, these sequences are extremely important, since they are –as far as I know– one of the few examples of teaching strategies used to assist and guide students in the articulation of scientific explanations that can be found in the literature. One possible way of continuing this research could be to analyse the effects that such strategies may have on students' explanatory skills.

In summary, all the participant teachers design activities in which the elaboration of an explanation is a distinctive (though not necessarily significant) element. The process of elaboration is usually shaped through dialogic interactions between the teacher and the students. These interactions consist of a series of communicative moves that have particular functions, thanks to which the explanation is built. Some teachers organise these moves into systematic instructional sequences that give more responsibility, ownership, and support to the learners.

6.2.3. Q1c. How do teachers assess students' attempts to construct explanations?

One of the dimensions of my research in which I encountered more obstacles was the depiction of the teachers' Knowledge of Assessment of scientific explanation. This might be due to the inherent intricacies of capturing this PCK component (a reason that would justify why it is so difficult to find studies devoted to KAs) (Abell, 2007; Friedrichsen *et al.,* 2009)). It could also be, however, that my participants' knowledge about how to assess student-made scientific explanations was insufficient and/or implicit. Possibly, the final answer contains a bit of both.

In previous sections, I have noted the shortage of observed episodes in which a teacher asks a seeking-why question to her students for them to elaborate a complete explanatory account by themselves. This being the case, it is not surprising, then, that the occasions on which the participants can display any method, model, or tool for assessing this scientific practice are very rare. Indeed, in Adrian, Becca, Barney, and Alba's cases, I could not find any evidence of the possession and/or use of any specific model, strategy or instrument to formally assess students' products, abilities, and/or engagement in scientific explanation production.

At first, it might be thought that the teachers in my study do not know many diverse assessment instruments. A thorough analysis of their lessons revealed that they did possess and deployed a wide range of instruments, methods, and activities to assess different learning dimensions. These dimensions included, in some cases, students' proficiency in certain science practices (e.g., the design and execution of experiments). This shows that the participants were aware that there are many assessable aspects of science learning beyond factual knowledge, and that a single instrument can rarely capture them all.

Only Christian seems to possess some interest in, and knowledge about, how to formally assess students' explanations. Both in Figures 4.6.1.4 and 5.4.1.a, I represent different aspects of Christian's instructional sequence for teaching how to build a good explanation. Interestingly, the last step in the sequence requires asking students to re-formulate or enrich their personal explanations after having listened to one or more classmates. Christian even gives the students some time to re-write them. This could denote that he possesses some mental model –not necessarily well structured– for the assessment of the explanations elaborated by the students. Although there are some indications, this is difficult to corroborate, since Christian did not make this model explicit, neither during our interview nor during his lessons.

Methods of effective assessment not only include summative evaluations, but also informal and formative. In the observed episodes that I categorised as 'explanation building', there can be appreciated some informal strategies that teachers used to help students in the task of producing –or, more frequently, understanding– the explanation. These included questions, comments, and remarks aimed to gauge and/or monitor whether the students were following the reasoning process and assimilating the information provided. Adrian even corrected a students' reasoning error on the go (§4.3.1.4). Most of the supporting comments and questions that teachers made during an explanatory episode were aimed to steer students towards a canonical explanation, and no to help them improve their abilities to construct scientific explanations.

In summary, while the participant teachers have a general knowledge of assessment that they drew on to assess different dimensions of learning, they show no signs of having developed practice-specific strategies or tools for assessing students' abilities and understanding of scientific explanation.

6.2.4. Q2. What do teachers perceive to be the fostering and/or hindering conditions for the teaching of scientific explanation construction in the classroom?

As reported in the previous section, one of the difficulties I encountered from the beginning of my research was the low number of episodes in which a teacher asked his/her student(s) to construct a scientific explanation for a given phenomenon. Consequently, in the course of the investigation, I broadened my research focus to try to understand why teachers did not create opportunities for students to experience this practice, despite considering it one of the essential components of science.

It was Alba (the first participant I interviewed) who spontaneously detailed some of the reasons she believed make it difficult to implement this practice in the classroom. She first said that students' lack the necessary language and reasoning skills to construct coherent explanations. She also said that the Spanish secondary science syllabus is too long for the school time available. Barney agreed with this, adding that education inspectors and some student's parents exert a huge pressure on teachers to cover the entire syllabus, which causes them to focus on delivering conceptual knowledge rather than on promoting engagement in epistemic practices.

Another impediment cited by Alba was the high student/staff ratio. In his interview, Adrian also noted that large-size classes might hinder the introduction of practices that entail deep-thinking commitment, like explaining phenomena. A very similar answer was provided by Barney, for whom having too many students in a classroom does obstruct the introduction of practices that require long times for reflection and discussion, and that need to be performed thoroughly and consciously, like building explanations.

Finally, Alba added that the scientific education she had received, and her teaching training, did not equip her with the necessary resources to implement explanation-driven experiences in her lessons. In a similar line, Adrian pointed to the lack of resources that characterises the Spanish public education system as one obstacle to including approaches to learning more student-centred and practice-prone.

On the other hand, Barney was the only teacher who mentioned some elements of his school that may favour the inclusion of discursive and epistemic practices in the science classroom. He alluded to the support of both the leadership team and the teaching staff, which translates into a great deal of self-confidence, autonomy, and room for innovation.

In a pioneer study examining PCK in higher education, Fernández-Balboa and Stiehl (1995) remarked the effect that 'contextual barriers' may have over teachers' *in situ* instructional decisions. These included time limitations, a high number of students per class, a paucity of appropriate resources, students' attitudes, and some formal assessment issues. It is quite noteworthy that all the elements cited by my participant teachers –whether they were curricular and pedagogical obstacles, or enablers for the integration of explanatory practices in the classroom– are contextual, or external. Notwithstanding the above, numerous studies on argumentation and other science practices have demonstrated that the elements that have the greatest weight as shaping the design and development of learning experiences are teachers' beliefs (see-§5.3.1). None of my participants reported any internal obstacle for the implementation of explanation in the classroom, although from their observed practice, some can be inferred.

6.3. Implications of the study and recommendations for further research

Although the transformation is still far from complete (Lehrer & Schauble, 2006; García-Carmona, 2020) over the past decade, researchers have been gradually shifting towards a practice-based approach to science teaching (e.g., Crawford, 2014; Erduran, 2015; Crujeiras-Pérez & Jiménez-Aleixandre, 2018). This shift is permeating, rather slowly, official science curricula and standards (e.g., Singapore and the US). According to the science-as-practice approach, teachers should be able to generate opportunities for students to fully immerse in disciplinary practices (Christodoulou & Osborne, 2014; Stroupe, 2014).

One of the practices considered crucial in science education is the construction of explanations. Introducing this practice in the classroom requires teachers to have a particular form of knowledge, PCK, which has been the subject of my study. This thesis is one of the few pieces of research to date with this focus. Something we can learn from it is that teachers' PCK of scientific explanation can be enormously varied; this does not mean, though, that it is developed enough to prompt the design of learning experiences for students to gain competence in this practice. Considering this and other findings revealed and discussed in previous chapters, several implications and recommendations for researchers in science education, practitioners, and designers of professional courses may be suggested. These suggestions are outlined in the sections below.

6.3.1. Implications and recommendations for researchers

Although during my observations, I witnessed some interesting explanatory episodes, in none of them did teachers explicitly teach their students how to elaborate a complete explanation of a natural phenomenon. The lack of emphasis in this practice in the science classroom has previously been noticed by other scholars (e.g., Zangori *et al.,* 2013). One of the reasons why this may be the case for my participants is that, for them, becoming proficient in producing scientific explanations is not a primary educational goal. A complementary hypothesis I formulate is that teachers struggle to support students in explaining phenomena because there is a high level of ambiguity in how this objective is presented in science curricula and policy documents[49]. This answer could also help elucidate why the participant teachers could not give a clear conceptualisation when asked about their notion of explanation. Considering that they each used the verb 'explain' with between four and eight different meanings in their classes (Table 5.2.b), I think it is fundamental to specify what is referred to in these documents, for the sake of clarity and, consequently, instruction quality.

A well-articulated conceptualisation of scientific explanation should provide a comprehensive answer to three questions that are connected to the three dimensions that Duschl (2008) attributes to disciplinary practices (see Figure 2.3). These questions are: i) What is a scientific explanation? –conceptual dimension; ii) What are the criteria to assess what count as a good explanation? –epistemic dimension; and iii) What kind of structures and norms are necessary to sustain and promote the process of building an explanation? –social dimension.

We can factorise and tailor these questions to the educational context; thus, it could be asked: How should 'scientific explanation' be understood for educational purposes? How should/can teachers introduce scientific explanation into the classroom? With what purpose? How should/can teachers assess this practice? What specific structures should teachers create, and what activities should they propose, to stimulate the formulation of scientific explanations? What materials are needed for supporting the construction of scientific explanations in the classroom? That is, if we conceive the production of scientific explanations not only as a practice *to perform* but also as a practice *to teach*, some pedagogical factors come into play (Duschl *et al.,* 2007).

We can draw on the Pedagogical Content Knowledge theoretical framework to answer these questions, since PCK refers to the professional knowledge that defines and distinguishes teachers (Shulman, 1986). The previous questions can be connected to the knowledge of the role that explanation plays in science and science education (OTS), to knowledge about the assessment models and methods necessary to evaluate the quality of students-made explanations (KAs), and to knowledge about effective instructional practices to promote mastery in explanation formulation (KIS), among others.

[49] See Appendix A.1 for a complete disquisition on this proposal.

My study aims to be a starting point towards the elaboration of these responses. For example, the operational definition of 'scientific explanation' that I developed, together with the discussion on the PTDR model (Yao *et al.,* 2016) presented in Appendix A.1, could help teachers understand what concrete practice they are being required to implement in the science classroom. My analysis of teachers' instructional strategies, and the report of the enablers and obstacles for the design of explanation-driven experiences perceived by them, can also shed some light on the social dimension of the process of building explanations. The next step is to know which research avenues can be followed to continue what has been started here.

The original design of my research project was very different to what I eventually did. My initial idea was to gauge the applicability of the PTDR model of explanation (§2.5.4). This would take place within the frame of a series of group workshops I had planned to conduct in each school with the purpose of enhancing teachers' PCK of scientific explanation. I prepared a PowerPoint presentation and several activities to depict, justify, and apply the PTDR model. During the sessions, teachers would have time to reflect on their knowledge of how to teach how to explain. They would also be given opportunities to share that knowledge by engaging in discussions. This, I expected, could facilitate the transformation of tacit experience-based knowledge into explicit and articulable forms of knowledge (Loughran, 2004). Although they had initially agreed, once my investigation started, the teachers declined to participate in the workshops. The main reason given was lack of time, which I found understandable. I admit that I readily gave up on the idea of running the workshops on explanation. Reckoning the limited impact that such a short-lasting experience might have on teachers' instructional practice in the long term, I deemed it more imperative to focus on producing a detailed and accurate portrait of their current PCK.

The previous paragraph exemplifies one of the multiple doors for the study of PCK of scientific explanation that could be opened by future researchers. Another line for further research may derive from the fact that the theory of PCK itself is still under development (Davidowitz & Potgieter, 2016). Every year, there appear some academic papers aimed at providing better-articulated definitions –e.g., the Teacher Professional Knowledge and Skill model (Gess-Newsome, 2015)– and more precise measurement instruments –e.g., the CoRe and PaP-eRs (Loughran *et al.,* 2004), and the PCK Maps (Park & Chen, 2012)– for PCK. The rationale behind these papers is to increase the clarity, consistency, capturability, representability, applicability, and status of PCK among researchers and practitioners (Carlson *et al.,* 2015; Park & Chen, 2012; Loughran *et al.,* 2004). Numerous authors profess that, besides continuing to develop theoretical aspects of PCK, more applied studies devoted to topic-specific PCK are needed (Abell, 2008; Avraamidou & Zembal-Saul, 2005; De Jong *et al*., 2005). Only some voices claim for more studies that focus on the PCK of scientific practices (McNeill *et al.,* 2016; Davis & Krajcik, 2005). However, as I have argued, these are urgent, given the inexorable turn towards teaching science-as-practice, and the paucity of examples on this issue so far (Osborne, 2014).

Two powerful and widely accepted tools for the elicitation and representation of topic-specific PCK were proposed by Loughran and his team: the CoRe and the PaP-eRs (Loughran *et al.,* 2000, 2001, 2004, 2006). The CoRe –'Content Representation'– consists of a set of questions to elucidate what teachers consider to be the central ideas/concepts on a topic, and the factors that influence their decisions when it comes to teaching those ideas/concepts. The PaP-eRs –'Pedagogical and Professional-experience Repertoires'– particularise the CoRe to a classroom context by providing an account of specific aspects of teachers' practice; they are conceived, then, to offer an insight into PCK in action (Loughran *et al.,* 2006). The CoRe and PaP-eRs have been successfully applied to analyse different topics, including chemical equilibrium (Van Driel *et al.*, 1998), particle theory (Garritz *et al.,* 2007), molarity (Rollnick *et al*., 2008), electrochemical cells (Aydin & Boz, 2013), and polymerase chain reactions (Chan & Yung, 2015). However, as far as I know, they have not been utilised in any academic work to portray teachers' practice-specific PCK.

My initial research plan contemplated the utilisation of the CoRe and PaP-eRs both as methodological tools for data collection and as representational devices of teachers' PCK of scientific explanations. I intended to use them during my workshops to spur and guide group discussions (Cooper *et al.,* 2015) and individual reflections. As the workshops never took place, I decided to adapt these tools to the time and circumstances of my participants. Thus, I included some of the questions that teachers are asked when completing the CoRe in my interviews (see §A.4). Beyond my limited adaptation, a consistent and complete application of the CoRe and PaP-eRs to analyse teachers with proven experience in effectively promoting scientific explanation could provide a highly detailed picture of the PCK required to introduce this practice in the classroom. This work remains to be done.

One of the limitations of my study is that I focused on three of the five constituent elements of PCK (Magnusson *et al.,* 1999). The justification for this decision was eminently pragmatic; my participants did not make any explicit reference to the role of scientific explanation in the science curriculum, neither did they allude to the difficulties that students might encounter in the elaboration process. Therefore, I had no data available relating to the two remaining PCK components (KSC and KSU, respectively –§2.6). Circumscribing the research process to only one or more individual components is not an anomaly within the PCK literature (see, for example, Brown *et al.,* 2009; De Jong *et al.,* 2005; Kellner *et al.,* 2011). In the field of PCK of argumentation, Yilmaz and colleagues (2017) limited their analysis to typologies of instructional strategies (KIS), while McNeill and Knight (2013) dealt exclusively with teachers' knowledge of students' difficulties with argumentation (KSU), and the instructional strategies used to help students overcome these difficulties (KIS).

Scholars accept that acquiring a deep understanding of the various PCK components separately can contribute to enriching our overall comprehension of teachers' PCK (Park & Chen, 2012). However, this is not sufficient for the derivation of practical implications (Soysal, 2018). The complex and integrative nature of PCK (Friedrichsen *et al.,* 2011) makes the division between components unclear in practice (Grossman, 1990; Aydin & Boz, 2013). Therefore, it is necessary to investigate how the distinct components interact with each other to guide teachers' actions (Abell, 2008).

In recent decades, some authors have ventured to develop analytical methods to facilitate the identification and representation of the connectivity among PCK components. One of the first attempts was made by Henze, Van Driel, and Verloop (2008). These researchers used a series of interviews to disclose the structure of nine teachers' PCK of models of the Solar System and the Universe. Based on the data provided by the interviews, the researchers divided the participants into two groups with qualitatively different types of PCK. To illustrate how the interactions between PCK components evolved with time for each group, they used box-and-arrows graphs, where the boxes represented PCK elements, and the arrows, the connections. In the same year, Park and Oliver (2008) presented a model for analysing the relationships between the five PCK components of three chemistry teachers. The model was also based on qualitative data, which were collected through interviews and observations, and analysed through a combination of constant comparative and enumerative analysis. So, first, Park and Oliver identified regularities in the transcripts through an interactive process. These regularities were afterwards categorised and enumerated to be summarised in what they called the PCK Evidence Reporting Table.

Kaya (2009) went a step further, combining a qualitative methodology with statistical techniques to examine the interaction between components of pre-service science teachers' PCK of Ozone layer depletion. Kaya created a rubric to evaluate each PCK component –whether as appropriate, plausible, or naïve–. Then, she introduced the Pearson product-moment correlation coefficient to investigate the inter-relationships and intra-relationships among components. Similarly, Padilla and Van Driel (2011) used a combination of qualitative and quantitative approaches to analysing the integration between components and sub-components of six university teachers' PCK of quantum chemistry. The first step of the analysis consisted of coding the transcripts of the interviews they had conducted, to identify the different PCK components and sub-components. In the next step, Padilla and Van Driel calculated the relative frequencies of each subcomponent and used Principal Components Analysis (PRINCALS) to explore the relationships between them. Based on the PRINCALS, they drew a set of clustered graphs for each participant. A different quantitative approach is PCK Mapping. Devised by Park and Chen (2012) to capture the interconnectedness of PCK components, it has been used in recent years by numerous authors for different subjects and topics (Park & Suh, 2019; Akin & Uzuntiryaki-Kondakci, 2018; Suh & Park, 2018; Soysal, 2017, Aydin & Boz, 2013; Aydin *et al*, 2015). The elaboration of the map starts with the identification of PCK Episodes within a set of observations, in which at least two of the five PCK components must be explicitly connected (Park & Chen, 2012). Every connection that is identified receives a strength of 1. To draw the PCK Map, the frequencies of all the connections between any two PCK components are added together, and then a nodes-and-edges graph is generated.

There are then various methodologies that can be used to analyse the interactions among PCK components, some of which have proven to be very powerful. When I planned my research, I considered applying PCK Mapping to my cases. However, since only three of the five components of the Pentagon Model were present in the observed explanatory episodes, eventually, this would have been of limited value. In the same way that the identification and representation techniques presented here have been successfully applied to explore and depict the connections among components in teachers' topic-specific PCK, it would be fundamental to use them also to acquire a clearer and deeper picture of how components interact within PCK of epistemic practices.

The coding scheme I developed to analyse the communicative moves used by my participants in their explanatory episodes (§A.3.4) could serve as a qualitative analytical framework to indicate potential connections between PCK components. For example, when Christian asked his students to provide some keywords (E#4-Ch), he was using a particular instructional strategy (KIS) to foster students' autonomy to build scientific explanations for observed phenomena (OTS). It could be coded as an interaction KIS-OTS. Such a task would require, of course, external validation of my coding scheme, like that carried out by the group responsible for the SEDA framework (Hennessy *et al.,* 2016). This is another of the paths opened by this work that some researcher might consider following.

Another area of education researchers' interest and concern is how particular teaching strategies and/or learning activities are related to student outcomes and understanding. Yang and Wang (2014), for instance, examined the effect that a teaching model had on elementary students' ability to write scientific explanations. The model, which integrated three different types of activities –namely, Descriptive explanation writing activity, Concept mapping, and an Interpretive explanation writing activity– proved to be effective both in increasing students' conceptual understanding and in their ability to construct explanations. Similar examples can be found in Lizotte, McNeill, and Krajcik (2004), and McNeill and Krajcik (2006, 2008) (see §2.5.3). Something common to these works is that the strategies used to teach how to build explanations are proposed and tested by researchers, rather than by teachers. This is what makes Christian's (§4.6.1.4) and Becca's cases (§4.4.1.4) so interesting. Here, it is they who come up with a sequence of instruction which is consistently used in their explanatory episodes. One last proposal for building upon my research would be to analyse the influence that Christian's and Becca's instructional strategies have on students' ability to explain natural phenomena.

6.3.2. Implications and recommendations for teachers and educators

At this point, it is to be expected that the reader had been persuaded about two things: i) that there is a strong rationale for students to learn how to produce scientific explanations; and ii) that the introduction of this epistemic practice in the classroom calls for a specific type of knowledge by science teachers; namely, PCK. My case studies show that some teachers do not possess well-developed PCK of scientific explanations and, therefore, they are not sufficiently prepared to support students in becoming proficient in this practice. A crucial question, then, is how teachers can improve this particular knowledge.

One first answer to this question is 'through teaching experience'. In line with a well-established research tradition (Mulhall *et al.*, 2003), this work exposes the existing differences between the PCK level of the most experienced teachers of my sample –Christian, Becca, and Barney– and the most novice – Adrian and Alba. Scholars agree that teachers "are not 'born' with PCK" (Kind, 2009, p.186) and that teaching experience is, indeed, a primary source of enhancement (Van Driel *et al.,* 2002; Grossman, 1990).

However, as Friedrichsen and colleagues (2009) note, experience alone does not guarantee the building of a strong PCK, as this study illustrates for the case of explanations. To improve their PCK, teachers also need to participate in tailored professional development (PD) experiences (Simon *et al.,* 2006). Some researchers have proposed that such PD programmes should include activities that challenge teachers' fundamental knowledge and beliefs about teaching and learning (Henze *et al.*, 2008; Henze and Verloop, 2009); otherwise, it is highly unlikely that these will have a lasting effect on their practice (Windschitl, 2004). Van Driel and Barry (2012) argue that the complex nature of PCK demands PD experiences in which teachers can enact teaching strategies, and, even more importantly, reflect on those enactments. Nakiboğlu and Tekin (2006) add that, in order to be effective, the approach must be topic-specific, since no programme can fully cover all the general aspects of PCK that a science teacher needs (Magnusson *et al.,* 1999).

Although numerous studies have analysed the connection between science teachers' PCK progress and PD experiences (Van Driel *et al.*, 2001; Bybee *et al.*, 2003; Van Dijk & Kattmann, 2007; Loughran *et al.* 2008; Cohen & Yarden, 2009; Friedrichsen *et al.* 2009; Schneider & Plasman, 2011), limited research has centred on PD for epistemic practices (McNeill & Knight, 2013). Following the example of what some researchers have done for PCK of argumentation (Zohar, 2007; McNeill & Knight, 2013; Sengul *et al.,* 2020), it would be interesting to examine whether PD programmes purposely designed to address teachers' PCK of scientific explanation have any long-term effect on their practice. Hoffenberg and Saxton (2015) request that such programs should help teachers develop a deep understanding of what is meant by the term 'scientific explanation' and to learn effective practices for teaching how to build explanations – two areas in which my participants showed room for improvement. As I described in the previous section, the PTDR model (Yao *et al.,* 2016) could act as the cornerstone on which to build workshops aimed at strengthening teachers' PCK of scientific explanation.

According to Aydeniz and Kirbulut (2014), any improvement in PCK "takes time, reflection, experience, and collaborative analysis of student practice and work" (p.161). During their education and training stages, prospective teachers see themselves as learners within a community of learners, and are open to scrutinise and reflect on their knowledge and beliefs (Bryan, 2003). Therefore, it has been suggested that something more effective than designing PCK-guided PD experiences for in-service teachers could be to include PCK in undergraduate preparation and pre-service teacher training programmes (Coe *et al.,* 2014).

Since Shulman (1986) proposed it, several researchers have investigated pre-service teachers' PCK in science (e.g., Lederman *et al*., 1994; Van Driel *et al.,* 2002; Nuangchalerm, 2012). These studies show that, quite often, their PCK is superficial, flawed, and inconsistent (Kaya, 2009). For example, in her single-case study of the Orientations towards Science (OTS) of a pre-service elementary teacher, Bryan (2003) identified two conflicting views about science teaching. While in her practice, the participant exhibited a teacher-centred approach, when describing herself as a teacher, she talked in terms of a student-centred view[50]. Similar findings were detailed by Crawford (2007), who found that the five student-teachers enrolled in a one-year science-as-inquiry course hold a broad spectrum of beliefs about science teaching, many of them contradictory. Many years before, Tamir (1983) had already reported that the conceptualisations of science of prospective teachers who participated in an inquiry-based learning program were incongruent with those proposed by philosophers and historians[51].

Another area of research on pre-service teachers has focused on studying the interplays that occur between different components of their PCK. Most of these works centre on the connections between two components –e.g., KSU and KIS (Penso, 2002; Halim & Meerah, 2002; De Jong *et al.,* 2005). Although valuable, these partial analyses do not provide clear guidelines about how to integrate all the components in a coherent way, which is a requirement to amend the quality of the whole PCK (Magnusson *et al.*, 1999) and to put it into action (Abell, 2008). Therefore, more studies with a holistic conception of PCK are needed. One of these studies was made by Krauss and collaborators (2008), who revealed that prospective teachers' PCK displays a lower degree of connectedness between components than that of the experts. Gess-Newsome (1999) had referred to this feature as 'fuzziness'.

These findings have led researchers to wonder how PCK can be enhanced during the education and training periods (Hagevik *et al.,* 2010). As with PD experiences, the success of any preparation programme/course on this task is contingent on prospective teachers having: i) opportunities and tools to improve their reflective thinking skills (Osborne, 1998); and ii) opportunities to apply the knowledge they acquire to authentic teaching activities (Loucks-Horsley & Matsumoto, 1999). Bryan and Abell's (1999) single-case study shows how complementing teaching experiences with reflections can contribute to breeding new insights about teaching specific topics, which, in turn, may translate into the advance of professional knowledge.

Following these guidelines, some educators have launched explicit PCK-oriented preparation programs aimed at refining pre-service science teachers PCK, with very positive results. For instance, Loughran and colleagues (2008) used a PCK-guided approach through the CoRes and PaP-eRs that they had developed (§6.3.1) to frame pre-service teachers experience about learning to teach science. According to these authors, this frame offered the participants both a conceptual and a reflection tool that "helped the[m] go beyond the more traditional

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[50] This situation is very similar to what I found in Adrian and Alba's cases (see §4.3.1.1 and §A.8.1).

[51] It must be said that all the experiences reported in these studies were discipline-specific but no topic-specific –nor, of course, practice-specific.

gathering up of a range of 'tips and tricks' about how to teach, and encouraged them to begin to delve into deeper understandings of practice based on better linking of teaching and learning purposes." (p.1316). A similar approach was followed by Nilsson and Loughran (2011) with a group of 12 prospective elementary science teachers during a one-semester course. The quantitative and qualitative results of their study show an explicit evolution in the participants' knowledge and skills for teaching the topic of 'Air'. Finally, Hume and Berry (2011) explored the case of a science-teacher educator who used CoRes to introduce, model, evaluate, and develop certain awareness of PCK within nine Chemistry student-teachers enrolled in a two-year training programme. The analysis of the material collected throughout these two years attested the potential that the CoRes had for PCK improvement.

Something on which these authors agree, and that has been known since the pioneering works in the 1990s, is that the development and increasing sophistication of pre-service teachers' PCK is a slow, tortuous, and non-linear process (Veal *et al*., 1999). First, because each individual's starting point is different; pre-service teachers present a huge plurality of backgrounds when they begin their training, in terms of experience, content knowledge, epistemological sophistication, and worldviews (Aydeniz & Kirbulut, 2014). Second, because PCK includes teachers' orientations and beliefs, and these are very hard to change (Jones & Carter, 2007). Third, because the aforementioned complex nature of PCK (Loughran *et al.,* 2004; Park & Chen, 2012) requires that each component be considered separately, but their integration must also be attempted (Hashweh, 2005). And finally, because each science topic (and practice) has its peculiarities and subtleties, so courses intended to improve PCK in too general terms could be rendered ineffective (Magnusson *et al.,* 1999). Therefore, educators who want to design initial teacher education programmes to help pre-service teachers develop sophisticated PCK need to identify what knowledge and beliefs they do possess and which they are expected to acquire.

This has been done with topic-specific PCK (e.g., Kaya, 2009; Nilsson & Loughran, 2011; Rollnick & Mavhunga, 2016) and, to a much lesser extent, with practice-specific PCK (Zembal-Saul, 2009). De Sá Ibraim and Justi (2016) discussed what is needed to plan and perform argumentation-based teaching, with the idea of using this as a basis for the design of practice-specific teacher training programmes. The authors propose that a strong PCK of argumentation would require teachers to have well-developed knowledge about i) the general structure of an argument –summarised on the CER model (§2.5.4); ii) instructional strategies and materials that can be used to create a learning environment where opportunities for argumentation may arise; and iii) particular actions to encourage students to participate in those opportunities. De Sá

Ibraim and Justi suggest that if future teachers were able to connect all these pieces of knowledge, they could guide students towards mastery in their argumentative skills.

To my knowledge, no one has accomplished such a task for scientific explanation yet. For both pre-service and in-service teachers to develop robust PCK to support students in the process of producing explanations, they must have the opportunity to participate in educational and professional experiences specifically designed for this purpose. And this requires, in turn, that educators are clear about what they want teachers to know about this epistemic practice. My study, with all the limitations which its context-dependent and exploratory character may entail, it is a first step in this direction, but it should not be the last.

6.4. Limitations of the study

The answers provided to my research questions may contribute to creating a coherent picture of the existing situation about how students are taught to build scientific explanations, and to developing some understanding of the possibilities for promoting this epistemic practice in science lessons. The scope of such contributions will be determined by the limitations this study presents.

In this section, I make explicit, reflect about, and try to justify the assumptions and limitations that arose during the research process (Creswell & Miller, 2000). This acknowledgement may help the reader interpret my findings, judging their rigour, and evaluating to what extent they can be generalised to other contexts (Maxwell, 2013). Specifying potential limitations can also suggest more directions for future research (Creswell, 2013).

6.4.1. First potential limitation: this is a multiple case study located within ERP2

Qualitative-interpretive research in Social Sciences (including Education) has been the target of many criticisms concerning the reliability and validity of its findings (Lacey and Luff, 2001). Many authors (Golafshani, 2003; Howell, 2013; Lincoln & Guba, 1985) agree that the terms ‘reliability’ and ‘validity’ are rooted in positivist perspectives. However, they do not consider that these terms should be rejected but redefined for a more suitable use in naturalistic approaches. The rationale behind this assertion is that, regardless of her ontological and epistemological assumptions, any researcher pursues rigour or ‘trustworthiness’ (Lincoln and Guba, 1985) in the enquiry process. What it is needed, according to them, is the definition of some paradigm-specific criteria for addressing rigour in qualitative-interpretive studies.

In the ERP1 tradition, the criteria that are said to be more commonly used to assess the quality of the research are internal validity, external validity, and reliability (Campbell, 1975;

Gibbert *et al*., 2008). Guba and Lincoln (1985) argue that internal validity –which refers to the extent to which two variables can be viewed as causally connected– should be displaced by 'credibility' in qualitative-naturalistic studies. On other hand, they suggest substituting the troublesome criterion of external validity –or generalisability of causal relationships– for the notion of 'applicability'. They offer some techniques to improve credibility and applicability of interpretive study findings, including: a) prolonged data-gathering on site; b) triangulation –that is, the use of a variety of data sources-; c) member checking –consisting in feeding provisional findings back to the participants to see if they regard them as a reasonable account of their experience; d) development of thick descriptions –by making visible the context of participants' social worlds; and, when possible, e) engagement in peer consultation.

Johnson (1997) follows the path sketched by Guba and Lincoln, but he makes a different proposal. Instead of replacing internal and external validity by other terms, he discusses three new types of validity for qualitative-interpretive research: descriptive validity, interpretive validity and theoretical validity. Descriptive validity refers to the degree of accuracy of a report as narrated by the researcher. Interpretive validity refers to the degree to which the research participants' viewpoints, thoughts, feelings, and experiences are understood by the researcher and portrayed in the report. Finally, theoretical validity refers to the degree of credibility in producing a plausible and coherent explanation of the phenomenon under study rooted on the empirical data. The strategies that Patton proposes to increase these three kinds of validity coincide with Guba and Lincoln's criteria for credibility and applicability. But he also suggests to (a) use multiple observers; (b) be aware of any kind of bias; (c) be critical and reflective with one's own reports and (d) use low inference descriptors, so that the reader can easily experience the participants' language and meaning (Goetz & LeCompte, 1993). In so far as to produce a high-quality report of my research findings, I kept in mind all the criteria proposed by these authors during my research. The only exception was the participation of more than one observer during the lessons.

Another term that needs to be rethought under ERP2 is 'reliability'. For positivist research, 'reliability' is concerned with the extent that an observation or an experiment can be repeated or how far some given results are replicable (Golafshani, 2003). In view of this definition, it is not surprising that there are authors who claim that the concept of 'reliability' is irrelevant in qualitative research (Stenbacka, 2001). However, just as with the idea of validity, the criteria for reliability in positivist-quantitative studies can be redefined to become more suitable for EPR2 research. Guba and Lincoln (1985) suggest the term 'dependability' as an analogue to reliability. The idea is that a researcher needs to demonstrate to the reader that the methods used for data gathering and data analysis are reasonable, consistent, and reputable (Denscombe, 2010). Thus, if the researcher is able to i) describe the procedures for data collection and analysis; ii) justify why these are appropriate within the context of the study; iii) clearly document the process of generating themes, concepts or theories from the data; and iv) refer to external evidence –including previous studies, then trust in the research process will emerge (Howell, 2013). These have been the criteria that have guided not only my investigation, but also the writing process of this thesis.

6.4.2. Second potential limitation: the number of participants of the study is small

Case studies require large amounts of data in order to create rich descriptions (Patton, 2002; Yin, 1994). This, coupled with the recommendation to use several cases to address trustworthiness and credibility (Lincoln & Guba, 1985), results in a possible limitation in the depth of analysis (Yin, 1994). For this reason, many researchers select no more than four cases to work with (Creswell, 1998). As I described in Section 3.5, the bulk of the data collection for this study was carried out with five teachers from three different schools in Seville and Madrid (Spain), and in Cambridge (UK), although only three of them are reported in detail in the main text.

A small sample does not necessarily make a study deficient. However, in small-scale research, one must be aware that the nature and the scope of any claim made may need some adjustment. The second issue to discuss in this section, then, comes from two epistemological questions: is it possible to generalise the findings from a specific study that makes use of a limited, exploratory, and purposive sample? If so, in what way? This has been a common subject of debate in the academic literature for decades (Bassey & Coate, 1999; Merriam, 1988; Stake, 1995; Yin, 1993, 1994). Although different authors make different proposals, all of them agree that a new understanding of the term 'generalisability' is required for questions concerned with understanding the meaning and complexities of contextualised studies (Donmoyer, 1990).

Stake (1995) recognises that case study does not provide a strong base to generalise to the population as a whole. This does not mean that case study is not worthwhile, however, because we can still learn from them. Stake introduces the term 'naturalistic generalisation' to define a process of generalisation based on similarity, in opposition to 'propositional generalisations'. According to this author, the descriptions generated in case studies should resonate with the experience of the potential readers, thereby facilitating their understanding of the phenomenon under scrutiny. The more similar the circumstances and individuals involving the particular phenomenon are to the ones that the reader wants to generalise to, the more defensible the generalisation will be. Naturalistic generalisations require research reports to be as rich in details and accurate as possible, so that readers can identify whether the findings can apply to similar situations.

Bassey (1981) had previously claimed that generalisations made from large statistical samples are not very useful to individual teachers. According to him, what teachers need are in-depth portrayals of particular cases that they can relate or apply to their own experiences and decisions. Bassey refers to this property as 'relatability'. He states that "if case studies are carried out systematically and critically, if they are aimed at the improvement of education, if they are relatable and if by publication of the findings they extend the boundaries of existing knowledge, then they are valid forms of educational research" (Bassey, 1981, p.86). Zeichner and Liston (1996) argue that studies with high relatability might help teachers to conceive and picture certain aspects of their work in previously inaccessible ways.

I am aware that, strictly speaking, the implications from my study only apply to my participant teachers in a very particular situation. However, as I have tried to make clear throughout this thesis, the primary purpose of my study is not to generalise from my participants to a population, but to identify, portray, and explore some specific knowledge, ideas, and beliefs about how to teach, guide, and scaffold the construction and evaluation of scientific explanations in science classes. Thus, while the scope of my study is limited, it is hoped that my sample teachers might have similar characteristics to other teachers, and that their experiences with this epistemic practice can be relevant to others, including those working in initial teacher education and teacher PD.

6.4.2. Some intrinsic limitations of the data collection and analysis procedures

As exposed in Section 3.6.1, I decided to play the non-participant-observer role in gathering my data, despite being aware that this research method might be subject to bias. First, because what we see and interpret is determined by the personal conceptual frameworks we have developed from our experience (Simpson & Tuson, 1995). Secondly, because observations are filtered through the understandings, preferences, expectations, interests, and beliefs we have as researchers, including some concepts and theories brought into the observational setting (Pring, 2000). I, for example, had a commitment to a particular characterisation of scientific explanation, sketched from my background knowledge from Philosophy of Science. At first, this led me to conclude that the participant teachers were not including explanatory practices in their lessons, even though they claimed to. A slight change in perspective (closer to actual classroom practice than to my preconceptions) allowed me to broaden my research horizon.

I must add another two possible sources of drawbacks: i) during observations, my presence in the classroom had an inevitable influence on the people being observed[52]. Giving the participant students and teachers time and space to get used to my presence helped to mitigate the starting disturbances. However, I cannot assure that all the teachers would have behaved the same had I not been there; and ii) since I was not allowed to use a video recorder, the lessons were just voice recorded. Fieldnotes were employed to compensate for the lack of images. These fieldnotes included visual aspects of the teaching environment, such as the information written on the board, classroom layout, and interactions between the teacher and the students and among students. The transcriptions of the voice recordings were merged with the fieldnotes to obtain a more exhaustive picture of how teaching occurred in the classroom.

I will conclude with a comment on the potential weaknesses that may derive from the translation I performed as part of the data analysis process. Adrian, Alba, Barney, Becca, and I are all Spanish native speakers. The interviews conducted with these participants were in our mother tongue. In addition, almost all the classes I observed in schools A and B were in Spanish[53]. The episodes that were originally in Spanish were translated into English for further analysis. I accomplished all the translation work. As reported in Section 3.7.1, all recordings were transcribed verbatim and arranged chronologically to produce a narrative document for each participant. From each of these documents, only those fragments I deemed relevant to my research questions were translated into English for subsequent coding. A second document containing all the episodes classified as 'explanation construction' (which served as the basis for analysing the PCK of each teacher) was elaborated. The translation of the PCK documents was also performed before the coding was carried out.

Translating is not an algorithmic, straightforward, and perfect process (Taber, 2018). Squires (2009) affirms that good translation for research purposes requires "the investigator to have a high-level sociocultural competence and significant background knowledge about the country and/or place of study" (p. 280). Having lived for 30 years in Spain made me completely familiar with the Spanish educational context. I cannot say the same about England, because when I started my fieldwork there, I had only been in the country for two years. This unfamiliarity with the English context and terminology was an added challenge to my

[52] See footnote 10.

[53] Some of the lessons I observed in Adrian's case were in English, and I also attended a couple of lessons in French with Alba.

transcriptions, my translations, and some of my interpretations. Since my supervisor (nor any other scholar directly related to this research) does not speak Spanish, he could not act as an independent reviewer to validate the technical and conceptual accuracy of my translation; having independent checks of the translations could have enhanced the study's trustworthiness.

6.5. Concluding remarks: learning experience

Completing this thesis has been one of the hardest intellectual challenges that I have faced in my life as a learner. During the four years that it has taken, my growth as a researcher, writer, analyst, and critical thinker has been undeniable. Slow and tortuous, but undeniable.

Before starting my PhD in Education, my research experience had been limited to research projects in History and Philosophy of Science. The skills that desk-based research entails were quite useful to complete some parts of this work (e.g., the critical thinking skills needed for reviewing the academic literature). However, the uniqueness of empirical studies in Social Sciences demanded other skills that I had to develop along the way. To accomplish my research objectives, I needed to recruit participants, earn their trust, observe their lessons, listen to them, interview them, transcribe, translate, and interpret their words and behaviours. I also had to code, look for patterns, and be attentive to emerging themes. All this, while trying to keep my assumptions and biases to a minimum, which was not an easy task.

In the first lecture I attended in Cambridge as part of my training in methodology, we were told that research is an ongoing and never-ending process. These are two things that I could corroborate throughout these years; I started conceiving and projecting one type of study but ended up doing something very different to suit the flow of my enquiries. Moreover, I realised that although my case study addresses a gap in the field of PCK and scientific explanation, and provides potential answers to my research questions, this was not the end, since new questions emerged from my work.

All the arduous processes here mentioned required careful planning, hard work, and dedication. I can say that, despite some difficult moments, I have proven to have the necessary qualities to meet these demands. Despite the experience gained and everything I have discovered about myself, I still have a long way to go. This investigation has opened new paths that I hope to be able to travel someday. It is something I owe to María (§1.1), to my former students, and to all those who at some point were curious enough to ask 'why'.

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APPENDICES

A.1. TOWARDS A WORKING MODEL OF SCIENTIFIC EXPLANATION FOR THE SCIENCE CLASSROOM

As has been exposed in the main text body of this dissertation, science education research literature and science curricula in several countries have emphasised the importance of involving students in the practice of constructing their own explanations for natural phenomena as a pathway to enhance scientific literacy. Despite all the interest from academics and curriculum designers about explanation building, the reality is that the teaching and training of this disciplinary practice is frequently underemphasised in science classrooms (Zangori *et al.,* 2013). The question that this motivates is why should be so. There are some widespread responses, that include: 1) teachers possess a limited understanding of how explanations are developed and evaluated and, therefore, they find difficulties in elaborating scientific explanations (Erduran *et al.,* 2004; Haefner & Zembal-Saul, 2004); 2) teachers lack the appropriate skills and expertise to effectively guide and scaffold students' efforts to build scientific explanations (Yao *et al.,* 2016, Newton *et al.,* 1999); and 3) some teachers do not consider the production of scientific explanations as an educational goal in its own right (Sadler, 2006). I propose an alternative but non-exclusive answer: that teachers struggle to support students' efforts to explain phenomena because there is a certain level of ambiguity in how education documents and curricula present this objective. That is, the lack of an articulated conceptualisation about its nature and function makes it difficult for teachers to systematically teach how to build explanations (Russ *et al.,* 2008).

As some authors submit –and research into other science disciplinary practices, namely, argumentation, has shown– a good starting point to encourage teachers to include explanation construction in their classrooms is to have at their disposal a simple but well-founded working model (Magnusson *et al.,* 1999). Such a model should: 1) be able to provide the foundations for teachers to reflect both upon the nature of scientific explanations and upon the epistemic process of constructing good explanations in a social setting like a classroom; and 2) serve as both a design template and an instructional and strategical scaffolding tool to help students learn the logical structure of scientific explanations. A working model for explanation requires, then, making explicit the elements that make up the structure of an explanation, so that students (and teachers) can be clear about what counts as a scientific explanation, both linguistically and epistemologically (Woodward, 1989; Unsworth, 2001; Braaten and Windschitl, 2011). It also requires giving an account for how scientific explanations are actually elaborated within the classroom, through a process of reasoning that could make use of oral and/or written language (Tang, 2016). This might help students understand the logic behind the practice, improving their ability to perform (Kuhn *et al.,* 2000). In addition, it could allow teachers to distinguish different levels of performance, making it easier the assessment process.

As I presented in section 2.5.4, some of this work has already been undertaken by science education researchers. Even though authors like Osborne and Patterson (2011), Brigandt (2016), and Tang (2016) have argued that argumentation and explanation are two different linguistic acts, with different schematic structure and distinct epistemic functions, in the academic literature, the use of the CER model for the analysis of both practices is still widespread. Examples of authors who have simply tried to adopt the CER model for argumentation to portray and analyse also scientific explanations are abundant (Lizotte *et al.,* 2004; McNeill and Krajcik, 2006, 2008; Ruiz-Primo *et al.,* 2010). Much scarcer are those who have chosen to develop their own models; models that, in my opinion, do present some functional (Braaten and Windschitl, 2011; Andrade *et al.,* 2017) or foundational limitations (Tang, 2016). None of these proposals has reached the same degree of acceptance as the Toulmin-based CER model for scientific argumentation.

Yao *et al.* (2016) present the PTDR framework as a new attempt to model explanations in the science classroom, and I believe it should become the new paradigm in framing students' explanations. The PTDR model shares some similar features of the CER framework, but the philosophical foundations are distinct from each other. The PTDR model adopts all the elements of Hempel's D-N Model as basic components –phenomenon, theory, and data–, thus defining a simple schema for explanations. Yao and his colleagues add 'reasoning' as the fourth component, in an attempt to avoid some of the main critiques that Hempelian ideas have received through the years, like the asymmetry problem (Salmon, 1989).

Based on the PTDR model, we can say that, when students are asked to construct a scientific explanation, it is expected they identify the phenomenon to be explained, then recall and articulate some conceptual elements and empirical data that could be used to explain it, and last, but not least, try to make sense of the association between the information used to explain and the phenomenon needing explanation through a process of reasoning (see Figure 2.5.4). In what follows, I will unfold and illustrate this characterisation, by addressing the following points: 1) what teachers can expect students to explain; 2) what I mean by 'articulation'; and 3) how the process of connecting all these elements is. I will use the PTDR model (Yao *et al.,* 2016) as the guiding point to discuss these questions.

A.1.1. What can teachers expect students to explain? → The phenomenon component

In the PTDR model, the phenomenon component (the *explanandum*, in Hempel's terms) refers to the identification of the phenomenon under study. It is the reason behind any explanatory activity. It is very common that students' explanations are inappropriate and/or poorly detailed (Keil, 2006) and this might be because they find difficulties in recognising which facets of the phenomenon are relevant and should, then, be focused upon (Faria *et al.* 2014). So, the first step to start building an explanation is to understand which particularities of the phenomenon[1] in question need to be explained (Russ *et al.,* 2008).

When dealing with non-probabilistic phenomena, the explanatory problem can be expressed by the teacher in the form of a seeking-why question: 'why is it the case that 'p'?', where the place of 'p' is occupied by a statement describing the target phenomenon (Hempel, 1965). Van Fraassen (1980) holds that an interrogative of the form 'why is it the case that 'p'?' is a contrastive question, since it implies the question 'why it is the case that 'p', rather than 'p_1', or 'p_2', ..., or 'p_n'?' The propositions 'that p_1', 'that p_2' and so on, are alternatives to the proposition 'that p': each is incompatible with 'p' and with all the others, and they depend on the given context[2]. It might be helpful for students to make these hidden contrasts explicit in the description of the phenomena under explanation[3]. For instance, they could be asked why ice floats in water *instead of sinking*, why the sky is blue *and not red* or why when leaving a balloon in the direct rays of the sun, its volume increases, *instead of decreasing or remaining constant.*

[1] Hacking (1983) introduces a particular meaning for phenomenon. For him, phenomena do not exist before we try to explain them; when we isolate and frame particular aspects of nature, we are creating a phenomenon to analyse.

[2] The idea that contrasts are always incompatible is not held by some philosophers (see, for example, Lipton, 1990).

[3] This question can be replaced by 'how is that possible that 'p'?' for the case of stochastic phenomena. The 'seeking-why' explanations (Hempel, 1965) and the 'understanding-how' explanations respond to distinct but equally legitimate epistemic requirements (Kitcher, 1989). In cases of genuine probabilistic explanations (such as in the Quantum realm), the contrastive why-questions about the occurrence of the phenomenon itself are out of place. The final goal of these 'understanding-how' explanations is to give account of the occurrence of an event showing that its probability is not zero. Something that could be legitimate (although, maybe, not always pertinent to ask in terms of understanding the phenomenon) is 'why is the case that '$P(p)=q$' instead of 'q_1', 'q_2', …, 'q_m'?', being q, q_1, q_2, and so on, different values of probability. For simplicity, in this study I am going to focus on 'seeking-why' explanations, and therefore, we restrict our analysis to students up to age 16. But I am aware that for older students, the curricular model for explanation should be refined in some way.

In their paper, Yao and colleagues (2016) describe the phenomenon component as "*more objective and certain* than the claim component in the CER framework" (p. 10, emphasis added). I think that these adjectives may be confusing for both the science teachers and the students and, therefore, I would not use them in the educational context. Instead, what I would require is the phenomenon statement to be empirically founded (Weber, 1996). To give the specific status of 'empirically founded' to a singular phenomenon, individuals must either consider that their own observations contain sufficient evidence for it or that they have good reasons to believe that someone else has gathered enough observational evidence for it. Assigning the status of empirically founded to a singular sentence is sufficient but not necessary for accepting it; the individuals could have other reasons for accepting the statement. The empirically founded requirement may serve as a link with those reform documents which insist on the connection between evidence, explanation and understanding of the natural world (NRC, 2013).

A.1.2. What do I mean by 'articulation'? → The theory component

To make sense of reality, scientists develop theories. The inclusion of this component in the PTDR model may encourage students to think about theories as explanatory frameworks. Railton (1981) claimed that "theories broadly conceived, complete with fundamental notions about how nature works (…), not laws alone, are the touchstone in explanation" (p. 242). Like him, many philosophers of science conceptualise scientific explanations as attempts to move beyond descriptions of natural phenomena into theoretical accounts of how phenomena unfold the way they do (Achinstein, 1983; Nagel, 1961; Salmon, 1989). De Regt and Dieks (2005) explicitly affirms that "A phenomenon P can be understood if a theory T of P exists that is intelligible (and meets the usual logical, methodological and empirical requirements)." (p. 150). To be more precise, not only theories and laws, but also other conceptual structures such as abstract models and principles need to be used when building explanations (McCain, 2015). Perhaps a change in Yao's nomenclature could be proposed, from the 'theory component' to the 'conceptual component', but it would be interesting to know which of these two turns out to be clearer for science teachers.

There are some issues concerning the theoretical component that are worth highlighting:

1) For science teachers to effectively use the PTDR model to base their practice, they should possess a well-defined notion of what a scientific theory is. Many authors recognise that possessing such knowledge about the status of scientific theories would help teachers acquire

an understanding of the ontological and epistemological nature of science (Besson, 2010; Brigandt, 2016). However, there are studies that reveal that science teachers struggle with the meaning of 'scientific theory' and they conflate it with the notion of 'scientific law' (Dagher *et al*., 2004; Haefner & Zembal-Saul, 2004). Both concepts have been the subject of ongoing discussion among philosophers of science, and it is not necessary for teachers to be aware of all the details of such debates. However, there are some key points that should inform teachers' work in order to properly guide their students towards proficiency in science practices (for a more complete review, see Hodson, 1986): i) Scientific theories and laws are different in nature and they serve a different function. Laws are idealised entities that describe regularities and relations. On other hand, theories are complex entities, frameworks of related concepts, that provide a potential explanation or interpretation of natural phenomena (and laws), and also facilitate predictions. Consequently, a theory never turns into a law, not matter how strongly supported that is, as many people (including school students) may come to think (Taber *et al.,* 2015; Bell, 2004); ii) Both theories and laws have a scope over time; that is, have a provisional nature, in the sense that they would be abandoned if a 'better' alternative were to be proposed; that is, if new empirical evidence was presented, or a new way of conceptualising existing evidence was mooted that was considered superior (perhaps considered more economical, more coherent, having wider range of convenience, etc.). Given the nature of laws and theories, I would suggest that whilst both laws and theories are, as aspects of scientific knowledge, provisional, we would generally expect theories to be more open to revision than laws. As both laws and theories are conjectural in nature, then an explanation drawing upon a law or theory will cease to be canonical once that law or theory is no longer canonical scientific knowledge. This is important as students should come to understand the conjectural nature of scientific knowledge as a fundamental aspect of the Nature of Science.

2) Learning science concepts is not a unitary process, and students may sometimes learn concepts to a degree (e.g., to recognise them when the teacher refers to them; to define them verbally, to describe them, to apply them to make discriminations in familiar contexts, etc.) that is insufficient to have the ability to use them for explaining natural phenomena. This particular ability entails bridging a gap between general theories or abstract ideas and concrete events, facts, or phenomena. The OECD (2013) expresses this by saying that "demonstrating the competency of explaining phenomena scientifically requires students to recall the appropriate content knowledge in a given situation and use it to interpret and provide an explanation for the phenomenon of interest" (p. 15). To get this, students must be able to identify the domain of a theory –understood as the set of the specific types of events that the theory is proffered to

account for– and to instantiate it with respect to a particular situation. Ohlsson (1992) calls this process 'articulation'.

According to Ohlsson, students are not automatically capable of articulating a scientific theory just because they had understood its tenets and content, inasmuch as theories do not prescribe their own articulation. In fact, saying that 'a theory explains' is for him a misguided language habit, because, being rigorous, the abstract principles of a theory proclaim something about the world but do not explain anything, because they do not say how the theory is to be used. It is the person who articulates the theory who does the explaining. A second claim from Ohlsson is that the articulation of theoretical knowledge is problematic and challenging, and so students cannot be expected to spontaneously figure out the procedures for how to use it in concrete cases in different contexts. An example of this can be seen in the difficulties that students present to identify that electrostatic interactions follow Newton third law (see Taber, 2000). The articulation procedure, then, must be explicitly taught to most students and should include the elicitation of explanation patterns which students cannot, generally, derive or create on their own.

3) As I argued in §2.5.4, the CER framework may be suited for argumentation arising from empirical inquiry, but not for theoretical-driven explanations that aim to provide causal accounts of natural phenomena (Tang, 2016). Then, I find it important to recognise that the theory component is the main distinguishing element between the CER and the PTDR models.

Researchers and practitioners who employ the CER model to characterise scientific explanations have two options: to consider principles, models, and theories as some kind of data, or to include them within the reasoning component. I advocate the need to explicitly separate the theory component for the following reasons:

i) we must acknowledge that contemporary views in philosophy of science recognise that scientific theories contain theoretical concepts -such as atom, force, or gene- that are not definable in terms of observable phenomena. So, we cannot refer to them as 'data' or 'evidence'; and

ii) in some situations, there might be discrepancies between evidence and theories. In a seminal work, Kuhn and collaborators (1988) found that people have numerous difficulties distinguishing between evidence and the theory itself, and that when there was any discrepancy, it was either ignored or unrecognised. In cases where the degree of confidence in the theory in use was only moderate, the participants simply adjusted the theory to fit the evidence, without considering the implications of doing so. Ten years later, Chinn and Brewer (1998) studied how students responded when confronted with data that contradicted the theories they possessed. These researchers found that students (like scientists) present seven different patterns; they either: 1) ignored the data; 2) rejected the data; 3) excluded the data from the domain of the specific theory; 4) kept the data in abeyance; 5) reinterpreted the data while retaining the theory; 6) reinterpreted the data and made superficial changes to the theory; or 7) accepted the data and rejected the theory under suspect in favour of a different theory. This reflects the range of ways in which students understand canonical teaching that is inconsistent with their prior conceptions (Gilbert *et al.,* 1982). Since these ways of responding to contradictions between theory and data are very frequent, these two components of explanations should be clearly differentiated.

Nevertheless, most science education researchers who use the CER framework to model explanations include the theory component as part of the reasoning component. But as Yao *et al.* (2016) point out, with this movement, the reasoning component happens to be twofold, and this might make it more difficult for teachers to diagnose possible difficulties in the process of constructing explanations. The problem could lie in the recalling and the articulation of the scientific theory or might be related to the student's reasoning ability. On balance, the imperative role of the scientific theory, and the pursuit of a more accurate diagnosis method, suggest that the theory component should not be incorporated into the reasoning component nor into the data component, but clearly distinguished as a separated feature that students need to pay attention to.

A.1.3. How is the process of connecting all these elements? → The reasoning component.

The strategy of capturing what counts as an explanation only through the identification of its structural properties is erroneous, since explaining is a practice, a process that facilitates understanding (Friedman, 1974), and this requires evaluating information and making sense of the connections between all the components involved in the explanation. It could also be problematic from an educational view, since if teachers design activities that focus exclusively on the structural components of explanations, students may frame them as an opportunity to demonstrate that they know this structure, rather than working to meet a broader learning goal; that is, "doing the lesson" rather than "doing science" (Jimenez-Aleixandre *et al.,* 2000). Then, to avoid building explanations becoming a ritualised and meaningless practice, teachers must make it clear to the students that there is a final purpose in this practice, which is to give an account of why certain phenomena occur. And to do so, students will have to articulate and integrate their current scientific knowledge in a coherent way.

It is the integration between the relevant pieces of information on an explanatory net that distinguishes an explanation from a mere description of a phenomenon (Bateson, 1979) and that allows scientific comprehension (Friedman, 1974). So, when deciding whether a discourse is explanatory or not, it is important to consider the whole account that the explainer offers. If I adopt Evans' definition of reasoning as "the process by which knowledge is applied to achieve most of our goals" (1993, p. 561) and I accept that our goal when explaining is to try to make phenomena comprehensible by bonding pieces of information together into some coherent structure (Machamer, 1998), it is easy to understand why 'reasoning' should be added as the fourth component in an educational framework for scientific explanation.

When presenting the fourth component of the PTDR model, Yao and colleagues do not dwell too much on specifying what they mean by 'reasoning'; they merely refer to a classic definition of the term given by Lawson. According to Lawson (1978), scientists display in their work different sets of reasoning patterns that can be identifiable, such as the isolation and control of variables or the correlational reasoning. However, neither in this paper nor in others dedicated to the same topic (Lawson, 1985, 1995), is there an explicit reference to the reasoning patterns relevant to scientific explanations. We need, then, to establish which those patterns are.

An idea defended by many philosophers, historians, and sociologists of science is that science practices are rule-bound systems of epistemic actions (Chang, 2011). For the practice that is the focus here, this means that there exist certain sets of basic rules in terms of which the scientific community prescribes what counts as a good explanation. These rules specify the type of information sought in forming the explanation, and the kind of relations and properties that define the accepted reasoning patterns (Colombo, 2017). Keil (2006) refers to this set of rules that frame explanations as 'stances'. Kuhn (1962) expressed this same idea by saying that successful explanations become *paradigms* on which further explanations are modelled.

These rules -or paradigms, or stances- may vary across different stages of scientific development and in different disciplines of science, and even in the same discipline depending on the context[4]. I am aware that, in the present moment, different disciplines accept different explanation types, based on distinctive patterns of reasoning. We have, for example, the so-called asymptotic explanations (Khalifa & Gadomski, 2013), dynamical explanations (Halina,

[4] There might also be some cultural differences with respect to the dominant explanatory patterns (Keil, 2006)

2018), structural explanations in fundamental physics (Felline, 2018), evolutionary explanations in biology (Van Mil *et al.,* 2013), formal-mathematical explanations (Brewer *et al.,* 1998), and intentional and abstract explanations (Pincock, 2015). It is, then, quite naïve to simply affirm that there is one explanatory relation able to capture the totality of the explanatory practices of all scientific disciplines. However, it is undeniable that mechanistic explanations hold a privileged place in science and school science (Railton, 1981; Salmon, 1998; Besson, 2010; Zangori *et al.,* 2015), and for many authors the New Mechanistic approach (Glennan, 1996; Machamer *et al.,* 2000) provides the most successful account of a vast majority of scientific explanations currently available (Felline, 2018).

For my current purpose of developing a suitable curricular model, I am going to limit my discussion to the reasoning process in mechanistic explanations. By centring my attention only on this type of explanations, I am not seeking to detract from any of the other cited types of explanations or the philosophical debates about them. I have opted to focus on mechanistic explanation because:

i) It has philosophical, historical, and pedagogical value. In addition to the already mentioned defence that many authors have made of the (Causal-)Mechanistic conception for decades (§2.5.3), we may add the idea that "both historically and for students, progress in scientific inquiry is characterized in part by a shift toward reasoning about causal mechanisms" (Russ *et at*., 2008, p. 500), since it evidences the use of higher-order cognitive skills (Jonassen & Ionas, 2008). From another perspective, mechanistic explanations can help students understand the connection between science and technological applications, since they "provide guidelines for successful intervention in natural processes" (Brigandt, 2016, p. 30).

ii) It is arguably the most prevalent form of scientific explanation in science classrooms (Osborne & Patterson, 2011; Braaten & Windschitl, 2011). When students are asked to explain some phenomenon, what is often expected is for them to cite mechanistic properties relevant to the production of the phenomenon (Walker & Sampson*,* 2013), which may lead to the appearance of epistemically relevant conversations about data and theory (Windschitl *et al.,* 2018). This seems reasonable if we consider the topics covered by syllabi and National Science curricula at Secondary levels, in which the connection between macroscopic (the observable) and (sub)microscopic levels (the unobservable) has a leading role (Chin & Brown, 2000; Taber, 2013). An example of this essential connection can be found in genetics education (van Mil *et al.,* 2013).

iii) It has been the subject of numerous recent studies in the field of science education research, e.g., in the context of biology and molecular biology (Machamer *et al.,* 2000; van Mil *et al.,* 2013; Southard *et al.,* 2017) and in chemistry education (Becker *et al.,* 2016; Talanquer, 2018).

Simply stated, mechanistic explanations "explain why by explaining how" (Bechtel & Abrahamsen, 2005, p. 422). That is, a satisfactory mechanistic explanation requires providing a description of the mechanisms responsible for the phenomenon under study (being them consistent with relevant, canonical theory). This informs us about how the phenomenon came about, instead of why it was to be expected –as Hempel (1965) claimed)–.

Many authors that support this approach to explanations tend to identify mechanisms with a conceptual portrayal of a set of causes and effects. Springer and Keil (1991), for instance, draw the mechanisms that mediate physical and biological events as consisting of causal agents and causal processes, both of which must be specified in giving explanations. Carey (1995) claims that the domain-specific mechanisms that explain how one event (the cause) brings about another (the effect) are crucial to form a proper understanding in biology. Abrams *et al.* (2001) similarly affirm that students should construct mechanistic explanations, where physical causes of a phenomenon must be identified. For Hindriks (2013), a mechanism is taken to be a stable configuration of causal powers, and "modelling a mechanism is a matter of modelling its causal powers and the way they interact" (p. 529). Zangori and collaborators (2015) also connect mechanisms, causes, and models, by stating that mechanisms represent "causal factors that are not necessarily intuitive or accessible through observation; rather, they are hidden underlying factors that become visible through engagement with scientific modelling" (p. 959).

These characterisations are not exempt from controversy, since there exist some disagreements among researchers and philosophers concerning what a cause –or a causal process, a causal agent, or a causal power– is, and how the explanatorily relevant causes are to be identified (Pincock, 2015). Yet in developing a curricular model, I seek an optimum level of simplification suitable for a particular stage in the development of epistemological sophistication, and I suggest that these are complications that should be excluded from the model at this level. Thus, instead of offering an ecumenical definition of what a cause is, I follow the already widespread path in science education research that advocates the broadening of the informal notion of causality that most students exhibit when they are asked to build explanations.

As numerous studies show, when reasoning about natural phenomena, students rely on a series of default assumptions that distort the nature of the causality involved (Driver *et al.,* 1985; Grotzer, 2003) and could pose some problems for learning (Besson, 2010). Among other general tendencies, it should be highlighted that:

i) Students tend to compose story-like explanations, based on simple and linear causal sequences. In them, every cause is the consequence of an adjoining cause, and the potential effects are considered only one direction (Andrade *et al.,* 2017; Grotzer, 2003; Perkins and Grotzer, 2005; Taber & Garcia-Franco, 2012). This implies that students only acknowledge straight connections between causes and effects and omit intermediate steps or non-direct connections. Driver and colleagues (1985) had already pointed to the fact that when students make use of causal reasoning, they present a simple chronological sequence of one-cause-one-effect chain and neglect the reciprocity of interactions. Grotzer (2003) suggests that students should be introduced to different types of underlying causal patterns that go beyond simple or multiple linearity, including mutual, re-entrant (or cyclic) and two-way patterns. This would require considering nonlinear, indirect, bidirectional, and interactive relationships between the different elements involved. Other authors follow this same direction, like Keil (2006), who proposes four distinct patterns of causal relations -common cause, common effect, linear causal chains, and causal homeostasis- that should be known in order to construct complex explanations. Or Besson (2010), who distinguishes between simple, linear, reciprocal, and circular causality[5].

ii) Students tend to attribute the cause(s) of a phenomenon to the presence of an agent (Anderson, 1986). Clough and Wood-Robinson (1985) add that Secondary students often attribute human agency to non-human organisms, because they make use of anthropomorphic explanations to make sense of the natural world. Grotzer (2003) proposes that students should learn a range of causal patterns of reasoning that consider both agentive and non-agentive causes, going beyond the direct influence and including those that might be deemed passive, distributed and/or nonintentional;

[5] There is perhaps a role here for the spiral curriculum (Bruner, 1960) where students initially meet and produce examples of explanations that can be understood as linear chains, inasmuch as these story-like explanations may be powerful in providing scientific understanding (Sevian & Gonsalves, 2008). But later in Secondary education, they are expected to work with other more nuanced causal patterns, whose different uses and areas of application should be purposive and explicitly introduced by teachers (Keil, 2006).

iii) Students find it difficult to look beyond immediate constraints and events, which could be problematic since some phenomena include non-obvious and/or imperceptible causes. Another challenge is that students do not usually reason about extended temporal and spatial frames, which might hide causes that are simultaneous and/or non-contiguous, as well as time delays and spatial gaps between causes and effects (Spelke *et al.,* 1996). Another common error is that students tend to focus on changes as opposed to steady states, consequently failing to see a need to explain systems in equilibrium (Driver *et al.,* 1985). Finally, students should be aware of the existence of probabilistic causation, where the level of correspondence between causes and effects is broader (Grotzer, 2003).

iv) Students' explanations are strongly context-dependent (Driver *et al.,* 1985). As a consequence, when faced with novel contexts, they tend to reduce the degree of complexity of the task by focusing on a restricted set of causes and ignoring others that may be equally relevant (Andrade *et al.,* 2017, Faria *et al.,* 2014; Kang *et al.*, 2014; Zangori et al., 2015). It is also common to find students who complete their causal patterns with some common-sense ideas they find convincing (Taber & García-Franco, 2010), even if they are not canonical.

Mature Pedagogical Content Knowledge (Schulman, 1987) for scientific explanation should include an awareness of these difficulties exhibited by students to correctly attribute the causality patterns underlying a phenomenon, as well as knowledge about some instructional techniques to try to modify, refine or eliminate them.

Although developing causal explanations are indeed central practices for making sense of phenomena in many cases, and although most of the explanations addressed in school are causal (Osborne & Patterson, 2011), we should avoid the mistake of characterising mechanistic reasoning as relying only on causality. According to the new Mechanistic philosophy (Glennan, 1996; Machamer *et al.,* 2000), mechanistic reasoning concerns the understanding of the process(es) underlying the association between causes and effect (Russ *et al.,* 2008). This, in turn, involves describing how the organised components and activities of a system are responsible for its observed behaviour (Schauble, 1996; Grotzer, 2003) and regular changes (Machamer *et al.,* 2000). For some authors, mechanisms are entities (Craver, 2006; Zangori *et al.,* 2015), while for others, they are conceptual tools (Bechtel, 2006). Regardless of the ontological position which one subscribes, the most important thing for the science classroom is to emphasise their epistemological and explanatory ambition, since the elucidation of the underlying mechanisms conveys an understanding of the phenomenon under study.

Providing a mechanistic explanation requires the students to show how the different features of the phenomenon depend on the organisational features of the underlying mechanism. Ideally, this should include a reference to all the entities, properties, and activities that are important to every specific aspect of the phenomenon (Craver, 2006). These organisational features have both a spatial and a temporal dimension. Spatial arrangement of entities and/or activities involve: Localisation, Structure, Orientation, Connectivity, Compartmentalisation, Order, Ratio, Duration and Frequency, while temporal aspects refer to: Order, Rate, Duration and Frequency (van Mil *et al*., 2013).

It is possible to find some studies whose objective is, precisely, to analyse whether students use mechanistic reasoning when building scientific explanations (e.g., Brewer *et al.,* 1998; diSessa, 1993; Hammer, 2004; Schauble, 1996). Metz (1991) examined the explanations elaborated by 32 children from three to nine years old, classifying them according to their use of conceptual entities, actions, and relations. Metz found three phases of development among the participant children's responses, ranging from functional to mechanistic explanations. Similarly, Chinn and Brown (2000) encountered a correlation between students who display a deeper learning approach and their tendency to construct mechanistic explanations, in which non-observable theoretical entities and cause-effect relationships were used to explain phenomena.

One of the aspects that these papers do not address in an explicit manner –and that is fundamental so that teachers can effectively guide students on their way toward explanatory proficiency– is what specific elements comprises a mechanistic explanation. Russ *et al.* (2008) provides an attempt to clarify this issue. For these authors, when building a mechanistic explanation about a certain phenomenon, students should identify several elements –phenomenon, set up conditions, entities, actions, properties of entities and organization of entities– and relate them by a process of reasoning –called 'chaining', through which the explanation is constructed.

I find many similarities between the PTDR model and Russ' proposal. In both cases, the process of constructing an explanation begins with a (potentially contrastive) question about the phenomenon to explain: 'why is the case that 'p'?'. Secondly, what they call 'set up conditions' can be identified with the empirical data component, that is, the set of statements about singular facts that are relevant to the phenomenon under study and that must be elicited; these are the initial conditions or particular circumstances in Hempel's terms (1965), or the background knowledge in Weber's (1996). Third, Russ and collaborators talk about entities and their properties, and organisation to refer to those things that play an essential role in producing the phenomenon, along with the activities in which they engage (Russ *et al.,* 2008).

Although the relationship of these elements with what I have called the theoretical or conceptual component may seem less obvious, the nexus becomes clear when we understand that the framework defined by a certain theory entails a set of assumptions about the kind of entities and the type of processes that fall under the theory's domain (Felline, 2018). Thus, for example, Boyle-Charles's Law can be explained by using the kinetic theory of gases (and then, talking in terms of particles that move), or Mendel's ratios by using modern genetic theory (citing the mechanisms of gametes formation).

Finally, Russ's process of chaining is equivalent to the process of reasoning, and it refers to the interaction of the different parts (entities) of the mechanism. These interactions can be characterised as "relationship[s] between two or more variables in which an intervention that changes one variable will bring about a change in another variable" (Glennan, 2002, p. 345). Everything I have said in previous paragraphs about a broad notion of causality should be taken into account when describing this process of chaining. So, according to both the PTDR model and Russ and collaborators', what can be expected from students when constructing scientific explanations is that they apply some conceptual and empirical knowledge they already possess to acquire some insight into the structure of the world and into the workings of mechanisms underlying it.

A.1.4. Conclusion and final remarks

In this Appendix, I build on the assumption that a working model may act as a starting point and as a guide in any learning-to-teach experience (Magnusson *et al.,* 1999). So, if teachers are provided with a model of scientific explanation that may help them understand what an explanation is and what makes an explanation satisfactory, at the same time that can be used for instructional and analytical purposes, they will be better equipped to support students in engaging in the practice of constructing high-quality explanations (Andrade *et al.*, 2017; Erduran, 2007). This model should synthesise the broadly agreed idea that a scientific explanation is an account of why a particular natural phenomenon occurs (Van Fraassen, 1980; McCain, 2015). I have argued here that this account requires the articulation of some well-established scientific theories and concepts, as well as some background knowledge that must be identified as relevant information, in conjunction with the enactment of the logical connections between them. With this, a conceptual framework is set up, leading to some kind of understanding

(Friedman, 1974). My main goal in the Appendix has been then to present such a general educational model of scientific explanation, and to persuade the reader of its value.

One aspect to be addressed in future research is how teachers can develop some model-based standard schemes for assessing the sophistication of students' explanations, clarifying the extent to which students are able to identify phenomena, select and articulate theoretical entities and explanatory models, select the proper evidence from a set of data and link these components through the process of reasoning (that may include, in most cases, a fully detailed description of the mechanisms involved, whether these are causal or not). I take from the Pragmatic Model the idea that the appropriateness (and, subsequently, the quality) of an explanation is always a bundle of context-dependent pragmatic criteria, and therefore it must be assessed for each specific situation.

In more concrete terms, pragmatists hold that considering an explanation as a mere description of the relation between theories and facts is a mistake; an explanation is a three-term relation, in which the context plays an essential role. Let us imagine that someone asks us why Socrates died. We could give her some different answers: 1) because Socrates was a man, and all men are mortal; 2) because he ingested hemlock, which is a plant that contains a neurotoxin that inhibits the functioning of the central nervous system; 3) because he was accused of having corrupted the youth and of impiety to the Greek gods; and 4) because he placed higher value on the legal process than on his own individual life or his own evaluation of his guilt/innocence (and so chose not to be a fugitive). Although all these answers could be considered acceptable explanations, it is the context in which the question has been asked which would make the questioner choose one or the other: "explanations may be more or less appropriate (…) in the context depending upon whether the information they convey is seen as relevant, interesting, well-confirmed, etc." (Railton, 1981, p. V).

Van Fraassen (1980) presents one of the best developed pragmatic account of explanation. According to him, an explanation is not an argument or a list of propositions, but an answer to a 'contrastive why-question'. A why-question always arises in a certain context (characterised by a background of accepted theory plus information) and can be determined by three factors: the topic (which states the phenomenon to be explained), the contrast-class (a set of alternatives in which the topic is included) and the relevance relation between them. To evaluate the answer given to the why-question, we can: evaluate the answer itself as likely to be true (in the view of the specific context); try to see the extent to which the answer favours the topic against the other members of the contrast-class; and compare the given answer to other possible answers to the same question. Contextual differences in contrast-class and relevance relations can lead people to offer different explanations for the same event, all of them being acceptable. So, the adequacy of an explanation is not only a matter of a valid logical structure (Yao *et al.* 2016).

Depending on the phenomenon under study, the context in which the explanation is produced and the specific objectives they have in mind, teachers will have to decide what patterns of reasoning they want their students to acquire and use. According to these patterns they will determine which explanations are satisfactory and which are not. The acquisition and articulation of these reasoning patterns is challenging for students (Grotzer, 2003; Perkins & Grotzer, 2005), so science teachers will have to make a purposive effort for them to achieve proficiency in performing this practice.

A.2. PILOT STUDY

My pilot study took place in June 2017 –that is, during my first year as a PhD student. It involved a one-week period of naturalistic baseline observations of two science teachers –Christian and Caroline– in a school in Cambridgeshire (see §4.6), as well as online interviews with a couple of Spanish science teachers. The main purpose of this stage was to train and test my skills as a non-participant observer and as an interviewer, to pilot my schedules for interviews, and to gain some ideas about how to conduct the bulk of my subsequent fieldwork. All the participants of the pilot study were easily accessible, willing to participate, and available for the time proposed. These characteristics remit to what the academic literature terms as 'convenience sampling' (Creswell, 1998). I was aware that individuals of convenience samples are not necessarily representative of any population. However, as they can provide useful information about how to conduct the inquiry and to refine the research questions, I considered this type of selection suitable for my pilot stage.

TEACHER	CAROLINE	CHRISTIAN
SCHOOL	**C.** Independent School (Cambridgeshire)	**C.** Independent School (Cambridgeshire)
GENDER	Female	Male
EDUCATION	B.Sc. in Physics PGCE in Secondary Science	B.Sc. Environmental Chemistry PGCE in Secondary Science
TEACHING YEARS	4	14
TEACHING SUBJECTS	Physics, Science	Chemistry, Science
OBSERVED LESSONS	11	3
LEVEL/TOPIC	Y8: Combustion reactions and Precipitations; Y10, Ionic compounds and GCSE simulation, correction and management	Y8: Exoplanets; Y9: Mass and Weight; Y10: Electric circuits

Table A.2.a) Details of the participants in the pilot observations.

I spent one week observing Christian and Caroline. Table A.2.a summarises some information about them. As I wanted to observe the classroom dynamic under its natural state, Christian and Caroline were requested to teach as they had planned, without purposively integrating more practices about explanation construction just because I was there. Before my arrival, Christian had emailed the parents of their students to obtain consent for the children to be recorded, and for the data to be used for this research. All the parents gave their consent.

During the lessons, an audio recorder was placed near the teacher's desk. One video camera was also set up in the classroom. The camera was operated in the back to capture the entire class, although on some occasions, it had to be moved to better capture teachers' (inter)actions. The videos were primarily used as a backup source of data, although they sometimes provided supplementary data about teachers' behaviour. After each observation, I transcribed the audio and video records. By the end of the week, I had collected more than 20 hours of recordings.

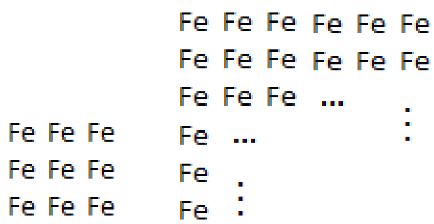
From this experience, I learnt that observations are not easy to accomplish. There are many unexpected events that may jeopardise the data collection. For example, one day my video camera ran out of battery, and I had to rely on the audio data for a couple of sessions. As the recorder was in a fixed position and Christian was continuously moving while teaching, I missed many parts. Since that day, I carried two batteries.

I also struggled with the transcriptions. Since English is not my mother tongue, sometimes I found it really challenging to faithfully write what teachers had said. When lecturing, they were interrupted by students, they often used informal expressions, did not always finish the sentences they had started, made some grammar mistakes, etc., all of which resulted in a remarkable number of hours of transcription work per hour of recording.

Apart from learning some practical tips that may were useful for the fieldwork stage of my research, what I really wanted to figure out with pilot observations was the potential of this method for investigating teachers' PCK of explanation. By using some preliminary codes for observations that I had adapted from the academic literature, I analysed the participants' lesson enactments to explore the opportunities they provided for students to engage in scientific explanation construction.

Among the 14 science lessons observed, I found two episodes classifiable as 'explanation construction', in which the teacher wanted the students to answer a seeking-why question. Both episodes occurred in Christian classes. For this reason, Caroline's teaching is not analysed. In Table A.2.b, I present a description of these explanatory episodes.

TEACHER	**CHRISTIAN**	
EPISODES	#1 and #2	
GROUP/TOPIC	OBSERVATIONS 6 AND 7: Combustion Reaction; YEAR 8	
DESCRIPTION OF THE EPISODES	In the first lesson, the eight students do engage in some hands-on activities to learn about combustion. First, they heat an iron nail for about one minute in a hot flame. But before they do, they are asked to write a prediction about what is going to happen. They work individually and quite autonomously. After a few minutes, they write their observations down. Christian, then, ask them to read aloud both their predictions and observations, highlighting that it does not matter if a prediction is wrong. After that, the students do the same with a piece of wire wool. Christian tells them that wire wool is composed of exactly the same element than the nail -iron-, but in a different form. Again, the students make a prediction before start heating the iron wool. After a few minutes, they seat and write their observations down, to comment out loud later. Finally, they take a spoon with iron filings and pour them on the Bunsen burner's flame. Once done, they share their observations and predictions. The last step is to try to explain why they find so different effects with each of the objects (nail, iron wool, fillings) despite having heated the same element (iron). Christian states that, in order to explain, students need some keywords and to put science into practice. He guides the construction of the explanation, with the students collaborating with some ideas and answers to his questions. Finally, Christian asks the students to write the explanation they have co-constructed with their own words, but as they lack time, he puts off the task for the next session. In the second lesson, Christian starts by reminding some aspects of the experiment of heating iron in different forms that they did a couple of days before. They read aloud the observations they wrote down on the previous section. Many of the students do mention a change of colour, and Christian tells them that a colour change is a trace of chemical reactions. He asks them to discuss in pairs what could be the iron reacting with in these chemical reactions. After a few minutes, one student say aloud that the iron reacts with the oxygen in the air. Christian, then, exhorts them to use Particle Theory to explain why each type of iron reacts with oxygen in a different way. The students discuss in pairs. Christian highlights the importance of using some key words to explain a phenomenon. He asks the students to write an explanation for the observed phenomena; they can use a diagram to better express their ideas. Christian says they must be accurate in language using. After writing, each student shares his/her explanation with a partner. Christian finishes the activity asking the students if there is anyone who'd recommend his/her partner's as an example of a good explanation.	
Type of Activity	**Inquiry-based**	*"Today's lesson is about predicting, then observing and then, later, trying to explain…so the idea for today's lesson is: 'can you use language to explain in words what's going to be happening?'"*
	Hands-on	*"What is your prediction for what's going to happen when you heat an iron nail for a minute at 750 ºC?"*
Type of Language devices	**Attention-focusing Qs**	*"Which was the most reactive? – [Iron filings]-. How many of you agree? Ok. Which was the less reactive? – [The iron nail…] -Ok, we all agree".* *"What we've seen here is a reaction, because the iron wool changes its colour slightly… how many people noticed that?"*
	Recall/ factual Qs	*"Which was the most reactive? – [Iron filings]-. How many of you agree? Ok. Which was the less reactive? – [The iron nail…] -Ok, we all agree."* *"What is the reaction between? What is the iron reacting with? – [Oxygen?] -The iron is reacting with oxygen, good… and where is*

		the oxygen coming from? – [the flame?] -No! – [The air] -Yes! It's coming from the air".
	Problem-posing Qs	*"You need to think about this, guys: 'can you explain why, if you are heating the same thing, the result is quite different… is there any way to explain what has happened? … that's the challenge!"* *"Ok, this, at the moment, is an iron nail. And, at the moment, there is 20% of the air that is oxygen. And it is hitting that at the moment, because air molecules, air particles, they are gas, they move around… this is being hit by air particles, but it isn't reacting… or is it? Why did it react when you did it in the lab and it's not reacting now? We can't see reacting…"*
	Comparison Qs	*"So, what is the difference, then, between the nail and the wire wool? Why does it react faster with the wire wool?" "Mmm, how is the surface area different between the nail, the wool and iron filings?"* *"When you heat the nail, how is that vibration different?"*
	Reasoning Qs	*"Here I have this piece of iron, which is in contact with the air… why isn't it now reacting with the oxygen? It hasn't got the energy, has it? It needs more energy… so, when the oxygen molecules are hitting the iron, barely it has enough energy to make the reaction, right? So, how do you think the iron is moving differently and the oxygen is moving differently if you heat them up? Why is the movement of the iron currently in this piece? – [silence]. -It's just vibrating. Vibrating about fixed positions. How does that movement change when we heat it up? – [It vibrates more] -yes!…*
	Explication	*"More heat means more vibration of solids ions, more movement. And actually, random faster movement for oxygen."*
	Examples	*"What we've seen here is a reaction, because the iron wool changes its colour slightly… how many people noticed that? It went darker, yes! Now, a colour change is a sign of a chemical reaction, all right? It could be…sometimes you get smell release, sometimes it's colour change, sometimes there is an explosion…"*
	Illustrations	*"How many atoms in this piece cannot by hit by an oxygen atom? Only one. And what's the proportion that cannot be hit? 1/9, great. If we have 6X6, how many atoms cannot be hit?*  *So, what's the proportion now of atoms that cannot be hit? 16 in 36, which is…4/9. Ok, is 4/9 more or less than 1/9. More, right. So, there are more atoms in this piece that can't be hit, ok?"*
	Reasoning	*"The surface area is bigger in the iron filings than in the nail. Look, there is iron in the middle of the nail, that the air cannot get to it, it cannot react but with the atoms in the surface… if you take the wire wool, you've got huge surface area where the air can get it, all right? And it's even bigger in the filings. Fantastic piece of science here! Surface area increases when the pieces get smaller.*

		And the opposite also, if the pieces get smaller, the surface area gets bigger".
Classroom management	**Individual work**	*"You are working on your own… everyone is going to make their own predictions"* *"Whatever you think is going to happen, you have to write it down, ok? And then later on, you can share that with the rest of us, tell us what your prediction was, and then, what your observations were.*
	Whole class interactions	*"We are going to listen to predictions and observations and then we are going to try to explain why if you heat the same stuff in the nail, in the wool and in the filings, all the same (iron atoms) there is a quite different effect."*
Explanation construction verbal support	**Using keywords**	*"Write down some keywords, remember, use science to explain it. Science that we have already learnt, and we put into practice".* *"That's something we'll need to put in our explanation: the nail has a small surface area."* *"What else do we need to put in here? Particle theory… more heat means more vibration of solids ions, more movement. And actually, random faster movement for oxygen."*
	Eliciting the phenomenon component	*"We are going to try to explain why if you heat the same stuff in the nail, in the wool and in the filings, all the same (iron atoms) there is a quite different effect. Think…what could be making the difference between the nail, the wool and the filings…"*
	Directing to necessary content (hint questions/ explications)	*"Here I have this piece of iron, which is in contact with the air… why isn't it now reacting with the oxygen? It hasn't got the energy, has it? It needs more energy… so, when the oxygen molecules are hitting the iron, barely it has enough energy to make the reaction, right?"* *"Why does it react faster with the wire wool? Mmm, how is the surface area different between the nail, the wool and iron filings? The surface area is bigger in the iron filings than in the nail".*
	Co-construction	*"Is there anyone who'd recommended their partner's as an explanation?"* *"We are going to read them out to our classmates to make sure that we have included everything, ok? (…). Let's have a listen to one or two of the others, and then we can see if they suggest anything that could improve our own explanation".*

Table A.2.b) Christian's explanatory episodes during the pilot phase.

Observations were revealed to be a powerful method for portraying the knowledge of instructional strategies (KIS) for teaching how to build an explanation. In these episodes, Christian deployed a wide range of language devices and instructional materials to support students' verbal explanation-construction, as part of a set of inquiry and hands-on activities. To engage them in this process, Christian asked a sequence of different kinds of questions. When a student proposed a correct (or interesting) idea, he used the strategy of paraphrasing the given response to make sure that the rest of the class had heard it, or made other student repeating the same idea with different words. As I had no opportunity to interview Christian, I can only presume that there is an intention behind this variety of instructional strategies, which would evidence a deep KIS for explanation construction.

I found more difficult to draw conclusions about Christian's orientations towards the role and nature of explanation in science education (OTS) by simply observing, because during his interventions he did not name what components an explanation should have, neither clarified what counts as a good scientific explanation. In this way, rather than postulating a general definition for scientific explanation, he made comments on particular accounts for an acceptable explanation to emerge. He did not even mention why it is important to find explanations for natural phenomena (the rationale behind the practice). That is, of the three practices that Lizotte *et al.* (2004) examine –namely, 'defining scientific explanation', 'making the rationale of scientific explanation explicit' and 'modelling scientific explanation'– Christian only used the modelling. He seemed to expect that after having verbally developed an explanation all together, students would be able to write their own explanations for the observed phenomena. Although Saglam and colleagues (2014) defend that students can learn what counts as a good explanation if they witness cases of acceptable and unacceptable exemplars, I doubt that this is the most effective strategy, because many students seemed to really struggle when they had to work on their own. Solomon (1986) backs up my impression when she states that mere ostensive examples of construction are insufficient for students to learn appropriate ways of explaining. This way of acting might reflect that Christian do not possess an accurate idea of the structure and the nature of an explanation. However, it could simply be the case that he does not consider it important for his students to achieve proficiency in this science practice.

Another aspect to note is that Christian did not mention whether he had the intention to assess students' explanations, so I cannot say whether he did have an accurate evaluation model or not. As Wang and Buck (2016) show, science teachers find many difficulties in the assessment of argumentation, and this could also be the case with Christian and the construction of explanations. I had not enough data to answer this query, though.

I realised that with the amount of data gathered for the pilot study it was not possible to draw any solid conclusion about Christian's PCK of explanations. Based on this, I determined that my fieldwork should take more than one week of observations. Another thing I learnt is that, to understand the reasons behind teachers' enactments –something essential to portray such a complex construct as PCK– it is necessary to complement observations with any kind of conversation. For this reason, I intended to conduct an informal interview with the two participants. Unfortunately, both teachers were quite busy at that time and they declined to be interviewed. However, they did agree to fill a ten-questions questionnaire about their teaching actions and beliefs about science. Only Christian sent it back. I thought that a questionnaire could be a reasonable (albeit poor) substitute for the interviews, given that some of the questions included were the same that appear in my interviews' schedules. I was convinced that it could help me obtain some insight of the rationale behind what I had observed. However, the only information provided by Christian was about his experience and training; the answers for the questions I was more interested in -those related to his knowledge of explanation- were too short, poorly nuanced, or unanswered. The questionnaire, then, was sub-optimal for obtaining data, but this failure reinforced my idea that interviews are the suitable method to complement observations for capturing teachers' PCK.

Convinced of the necessity of piloting my interviews' schedules in order to ensure whether the questions are appropriate for my objectives, and since Christian and Caroline had declined my offer, I invited two Spanish secondary science teachers, Adrian and Antonio, to undertake an interview by Skype. The conversations were recorded using a free software[6] and transcribed verbatim, to be afterwards translated into English. After this process, I made a refinement in wording and order of the questions, according to the suggestions made by the interviewees. Piloting also allowed me to specify the amount of time required for the interviews (Table A.2.c).

TEACHER	ADRIAN	ANTONIO
GENDER	Male	Male
EDUCATION	B.Sc. in Chemistry PGCE in Secondary Science	Degree in Architecture PGCE in Secondary Science and Technology
TEACHING YEARS	3	2
SUBJECTS	Chemistry, Science	Maths, Science
INTERVIEW TIME	35 min	39 min

Table A.2.c) Details of the participants in the pilot interviews.

The pilot stage provided some evidence regarding the suitability of semi-structured interviews as method for portraying teachers' PCK (some components, at least). Concretely, the interviews supplied insight into the participants' orientations towards science, including their understandings of scientific explanations and their beliefs about the importance of this scientific practice for students' literacy. In Table A.2.d, I show the responses that Adrian and Antonio provided to the questions 'What is science?', 'What is scientific explanation?' and 'What makes

[6] Retrieved from https://www.dvdvideosoft.com/es/products/dvd/Free-Video-Call-Recorder-for-Skype.htm

a scientific explanation a good explanation? Interviews also proved very helpful to identify the reasons underlying instructional practices promoting students' explanation construction.

ADRIAN	ANTONIO
"[Science helps us] understand why things happen"	*"Science is the set of knowledge about the dynamics (…) in our world, whether at the microscopic or macroscopic level, which allows us to be able to interpret what happens around us"*
"Scientific explanation is the way we demonstrate how [these] phenomena occur. That is, how we understand or verify that something happens"	*"[Scientific explanation is] the justification for a phenomenon"*
"A good explanation is the one that makes others understand that a phenomenon is explained trough that fact that has been shown"	*"Well… [a good explanation] should include a clear and concise language. It should also include, if necessary, a mathematical expression that includes the magnitudes involved in the phenomenon, and it must also include, …, mmm…, some answers applicable to modifications for different phenomena, not only for one. That is, it must have a somewhat global nature"*

Table A.2.d) Adrian and Antonio's beliefs about science and scientific explanation

A.3. PRELIMINARY CODES FOR OBSERVATION AND ANALYSIS

A.3.1. Codes of PCK components (adapted from Magnusson et al., 1999, and Wang & Buck, 2016).

PCK COMPONENTS	CODES	GENERAL DEFINITION	EXPLANATION-RELATED PCK
Orientations to Teaching Science	**OTS**	- Beliefs about how students learn and what should learn at different grades levels - Beliefs about what science is	- Knowledge of the role of explanation in science and science education - Know how to construct a good scientific explanation
Instructional Strategies	**KIS**	- Variations in teaching methods, strategies and instructional material - Classroom management	- Knowledge of the appropriate instructional strategies to perform the construction of explanations
Assessment of Science Learning	**KAs**	- Knowledge of the dimensions of science learning important to assess - Knowledge of the methods, instruments, approaches and activities by which learning can be assessed	- Knowledge of the approach to assessing students' performances in explanation construction

Students' Understanding	KSU	- Knowledge of what students know about a topic or practice, including: their prior knowledge and experiences, common conceptions, and misconceptions, learning difficulties, and plurality in learning styles, interest, abilities, motivations, and needs	- Knowledge of the students' background that would affect the construction of explanations - Knowledge of the types of pseudo-explanation more commonly used among students
Science Curriculum	KSC	-Deficiencies within curriculum and textbooks - Making inter-connections between courses and subject-specific units/topics/practices	- Knowledge of the implementation/adaptation of explanatory practices in the existing curriculum

A.3.2. Preliminary Codes for Science Teaching Orientations (adapted from Magnusson et al.,1999).

ORIENTATION	DEFINITION
Academic rigor	A particular body of knowledge is presented by challenging students with difficult problems and activities
Didactics	Delivering of facts of science through lecturing, that is, the teacher verbalises for a majority of the class time with questions often asked and answered
Conceptual change	Students are pressed for their views about the world and consider the adequacy of alternative explanations
Activity-driven	Students participate on *hands-on* activities
Discovery	Students take an active role in their learning process by answering questions or solving problems designed to introduce a concept or skill
Project-based science	Students are involved in investigating solutions to authentic problems
Inquiry	Students explore course content and learn to ask questions, make discoveries, and/or solve problems

A.3.3. Preliminary Codes for Instructional Strategies

INSTRUCTIONAL STRATEGIES	DEFINITION
ACTIVITIES	Student-centred strategies: actively involve students in shaping their own learning

Inquiry-based	Inquiry requires students to identify problems, formulate questions and devise answers, collect and interpret data, discuss, reflect and test the reliability of the knowledge they have generated.
Hands-on	Active physical manipulation of objects and materials associated with science concepts
Simulation	Mock events in which students are involved.
Problem-solving	Structured approach for tackling problems systematically by using the relevant concepts and principles. There exist domain-general problem-solving strategies (that one without any expertise in the domain at hand can draw upon) and problem-solving strategies specific to the domain.
Debating	Competitive discussion of different views within a topic between individuals or teams of students.
Role playing	Students act out roles followed by a debriefing to define what they have learned (Burden and Byrd, 2013)
Computer-based activities	Introducing computers in the classroom for educational purposes
LANGUAGE DEVICES and REPRESENTATIONS	Teacher-centred methods: Ways of representing and formulating the subject in order to make it comprehensible to students (Shulman, 1986).
Demonstration	Teacher exhibits or displays an experiment, process or skill to the class and discusses concepts embedded in lesson
Explication	Teacher explicates something to students to foster their understanding; that is, to create new connections between facts, concepts, and ideas
Mnemonic devices	Cognitive strategies for helping to learn and memorise facts, dates, rules, classifications and so on.
Questioning	Teachers pose content questions to have the student deal directly with the content taught, or pose process questions to guide, arouse curiosity, encourage activity, analyse, synthesise, to solve a problem or to make a judgement (Borich, 2011).
Illustrations and Examples	Illustrations are prototypes or detailed descriptions that serve to exemplify. Examples represent the concept being taught by including all the attributes essential for recognising that concept as a member of some larger class.
Narratives	Stories that help the students make personal or real-world connections to the content (Burden and Byrd, 2013, p. 183).
Models	The teacher or another student demonstrates a new concept or skill and students learn by observation and emulation.
Analogies	Comparison between two similar things that can be used to explain something or to make it easier to understand (Burden and Byrd, 2013, p.153)
Metaphors	Figures of speech, used to make an implicit comparison or connection between two unlike things (Burden and Byrd, 2013, p. 152)

A.3.4. Inductive Codes for Discourse moves

DISCOURSE MOVES	Description	
INITIATING MOVES	**The teacher begins a new thematic interaction episode**	
Initiating: cluster codes	**Description: The teacher…**	**Example**
Addresses a particular student's interest	Uses the particular interest of one student to open a new episode	***Ba.- Bianca is very interested, and so do I, in talking about life expectancy*** *(in fact, this is what I was going to talk about now and compare it between different countries). What do you want to comment on, Bianca? (…)* ***Why do you think life expectancy is those countries are those?*** *S6.- Well, from my point of view, and from what I have researched, these differences are due to the food of each country and the diets people follow. Because, for example, the Internet shows that the diet of the Japanese is very good.* (E#12; Y10.O4-Ba)
Asks for a connection to prior knowledge	Asks the student(s) to connect the topic/ problem/ question/phenomenon under study with something they already know	*Ba.- Why does this datum -73%- come out?* ***Does that correspond to what you know?*** *S1.- Well, not exactly.* *Ba.- Not exactly, why?* *S1.- Because we do not have a very large sample.* (E#16; Y11.O5-Ba)
Asks for an opinion	Asks the student(s) to express their opinion about the topic/ question/ problem/ phenomenon under study	*S1. From the age of 30, as [people] get older, there are fewer deaths due to external causes.* ***Ba.- Why? Now I'm going to ask for your opinion. Why most people who die due to external causes are in that age group?*** *S1.- Because at that age they take more risks*. (E#10; Y10.O4-Ba)
Asks for a prediction	Asks the student(s) to make a prediction about a certain phenomenon	*Ch. –* ***Before you do, let's just think about it, let's make predictions****. So, we know that nothing really happened with water. With vinegar, which is a weak acid, you get quite a lot fizzing, what shows that a gas is made.* ***What's your prediction with HCl?*** *S1.– It will dissolve.* *Ch.– Ok, will it dissolve? Maybe. (E#11; Y7.O2.S-Ch)*
Casts/recalls students' attention	Poses a question/ makes a comment to cast student(s) attention	***Ba.- What has caught your attention in this document?*** *S1.- The increase in the number of deaths with respect to the previous year. It is weird that there is so much variation from one year to the next, both in boys and girls.* *Ba.- How would you explain that? I'm always going to ask you why you think that data are like that. This is a tendency that always occurs …* (E#8; Y10.O3-Ba)
Connects with an example	Establishes a connection between the current starting episode and a known example	***Al.- Let's see the car example. We have the force of the motor which propels it forward; that's why it moves, isn't it?*** *And the wheels? Because the engine may propel it, but, cars, carts, all these things move with wheels, right? What is it that turns the wheels?* *S1.- The motor.* (E#4; Y9.O4-Al)

A.3.4. Inductive Codes for Discourse moves

INITIATING MOVES	**The teacher begins a new thematic interaction episode**	
Initiating: cluster codes	**Description: The teacher…**	**Example**
Demonstration (introduces the phenomenon)	Introduces a new phenomenon though a demonstration	*Ch.– So, if* ***you got this bulb, and inside the bulb there's this very large amount of liquid****, ok? I'm just gonna colour it in red here. Most of these thermometers have alcohol in them, because alcohol, as phenol, is pure and clear transparent, which is not good, isn't it? So, they put a little bit of dye to make sure you can see it. In those one, it's kind of green. That one you've got is mercury.* ***Now, this liquid is expanding as your hands are around it. But the bulb is also expanding, because solids also expand. What's the difference between the way the glass is expanding…?*** *S1.– It's slower.* *Ch.– So, it's expanding less, isn't it?* (E#15; Y10.O2.P-Ch)
Direct instruction (new problem)	Sets a new problem/ question/ activity/ task and directly asks the student(s) to solve it	*Be.-* ***We are going to use a cooperative-work dynamic that we all know very well: the 1-2-4 (for us, the 1-2-table). You will have a minute to think individually, a minute to share as a couple, and a minute to reach agreement as a whole team****. I'm going to write an observation on the blackboard, and we'll get a question from it.* (E#3; Y9.O2-Be)
Experiment (introduces the phenomenon)	Introduces a new phenomenon though an experiment	Ch.– **You're gonna put your ink in this line, ok? This line. (…). Ok, now, Cristine, when you put the paper in, what can you tell us about the water and the paper? What does the water do when it hits the paper? Does it stay exactly where it was?** S1.– Ahm…, no; it goes higher. Ch.– It goes up. (E#14; Y8.O2.S-Ch)
Invites elaboration /reasoning	Invites the student(s) to clarify, paraphrase, extend, elaborate, or deepen an idea	*Ad.-* ***Could you explain what you have done?*** *S1.-First, I do decimal notation.* *Ad.-Ok.* *S1.- Then, I apply the conversion factor.* *Ad.- Ok, how many steps are there between metres and cubic decimetres?* *S1.- One step*. (E#1; Y9.O1-Ad)
Invites reflection	Encourages the student(s) to reflect about the phenomenon under study	***Ba.- I would like to invite you to reflect****. You said that [lettuce] can be seeded practically at any time. We're going to take advantage of the fact that he has commented on that to ... uh, in fact, we do it here, don't we? We seed it at any time. We have this planted and it is growing well, the lettuce. Why do you consider it important that you can seed lettuces at any time?* *S1.- So that we have more lettuce.[Laughs].* *Ba.- I think the question is not well posed, but well, I now reformulate it. Anne Laura?* (E#6; Y8.O8-Ba)

A.3.4. Inductive Codes for Discourse moves

INITIATING MOVES	The teacher begins a new thematic interaction episode	
Initiating: cluster codes	**Description: The teacher…**	**Example**
Reasoning Question	Poses a question that involves thinking, synthesis and analysis. The question may allow for personal responses and stimulate further discussion and questioning	**Ba.- Why are there more birds that eat our vegetables during the winter?** S1.- Because they feel attracted by the smell of the plants. S2.- Because they want to take the pollen from the plants. (E#1; Y8.O1-Ba)
Recalling/Factual Question	Poses a question for students to recall some factual knowledge	*Be.-* ***Do you remember that we saw the [concept of] solubility? What was solubility?*** (E#12; Y11.O1-Be)
Refers back to a prior session	Connects the current episode with a previous lesson	*Ch. – Open your books at the lesson when you were doing the neutralisation,* ***with that long thing burette, remember?*** *Excellent. Ok. Now, the first question for you this morning is* ***what were the names of the two chemicals that we were mixing?*** *So, we got sodium hydroxide at the bottom, and that was one chemical, and then,* ***there was a different chemical in the burette that you filled up. Can you remember the name?*** *work in pairs in ten seconds, just to remember the names of these chemicals.* (E#9; Y7.O2.S-Ch)
Refers back to a prior contribution	Makes an explicit connection to an idea that has previously appeared on the conversation…	*Ad.-* ***Why did you said that when we were talking about throwing a ball, it will stop sooner if you throw it in the beach, I mean, in the sand, than if you throw it in a skate park?*** *what's the different between both places?* *S1.- That in a skate park, the…* *Ad.- The surface…* *S1.- The surface is smooth, and in the beach, the surface is like the other way.* (E#20; Y9.O31_Ba)
Student's question	Uses a student's question as leverage to start a new episode	*S1.–* ***Why is it one minus (${}^{-}$)?*** *S2.– Because it's a non-metal.* *Ch.– Because it's a non-metal, and non-metals form negative ions. How many electrons are there in chlorine outer shell? Normally. Normally, how many. Which group is it in?* *S1.– Seven.* *Ch.– Seven electrons. So, when it gets one, it fills the outer shell. (E#12; Y10.O3.C-Ch)*
Makes a statement + recalling question	Makes a claim and poses a question that requires factual recall	*Ch.–* ***In here it's just neutral. Can you see that? How do we now get dry pure crystals of sodium chloride?*** *From this.* *S1.– Filter. – we don't need to filter anything! (E#13; Y10.O3.C-Ch)*

A.3.4. Inductive Codes for Discourse moves

DISCOURSE MOVES	**Description**	
CONTINUING MOVES	**The teacher provides the means for the students to continue to elaborate either their own or their peers' reasoning**	
Continuing: cluster codes	**Description: The teacher…**	**Example**
Asks for a clarification	Asks the student(s) to elaborate on the meaning of a term/ concept	Be.- [H]ow are the particles of the solid: quiet or moving? SS.- Moving. Be.- **And what was the name of that movement of solid particles?** SS.- Vibration. (E#3; Y9.O2-Be)
Asks for a definition	Asks the student(s) to clarify the meaning of a concept/ term	*Al.- **OK, and what's the deforming force?*** *S1.- The force you make to deform the rubber.* *Al.- That's it, it's okay. In Hooke's law, the deforming force would be F; and the deformation, what would it be?* *S2.- The elongation.* *Al.- The elongation, that is. Very well!* (E#3; Y9.O3-Al)
Asks for a demonstration	Asks the student(s) to justify a claim by using a numerical demonstration…	*S1.- That if you…, if the force you are applying to the object, if the object is, is, eh…, lighter, the acceleration, eh…, will be more…* *Ad.- Ok, we agree about that. I mean, we know that it's easier to move a light object than a heavy one. But now, **we have to demonstrate that information using numbers, ok?*** (E#7; Y9.O19-Ad)
Asks for a different participant	Tries to involve a different participant in the dialogical exchange	*Al.- One question: how many significant figures does this result have to have?* *S1.-One.* *S2.- Two.* *Al.- Why? Aitor will explain why. Tell us, why two?* ***S2.- I know they must be two, but I do not know how to explain it.*** ***Al.- Do you need help from someone? Come, on, Anne.*** *S3.- Because if you get the data with two significant figures, the result also has to have two.* *Al.- Ok, but the data ... we are given three data: 150, 35 and 45.* *S3.- And two of them, that is, almost all, have two significant figures.* ***Al.- Mmm…, Athenea?*** *(E#15; Y9.O3-Al)*

A.3.4. Inductive Codes for Discourse moves

CONTINUING MOVES	**The teacher provides the means for the students to continue to elaborate either their own or their peers' reasoning**	
Continuing: cluster codes	**Description: The teacher…**	**Example**
Asks for confirmation	Asks the student(s) to confirm their agreement with an exposed idea…	*Al.- There's almost no friction on ice ... Why do they use blades [referring to skaters]?* ***If there is no friction, they could skate with their feet, couldn't they?*** ***S2.- Yes.*** ***Al.- But they could not stop!*** *If there is no friction, how could they stop? They would land on their butts, and even so, they keep ..., right? So, they need blades, because when they want to brake or turn, and not to fall, eh…, they need to drive the blades into the ice to be able to stop, okay?* (E#4; Y9.O4-Al)
Asks for connections with prior knowledge	Asks the student(s) to establish a link between the phenomenon under study and some previous knowledge	*S1.- Because at that age they take more risks.* ***Ba.- Can we relate that to something we have learned about the brain? With what?*** *S2.- With oxytocin. More teenagers die because they take more risks because oxytocin levels in their brain increase and one of the effects is that ... [they] value the reward more than the risk.* (E#10; Y10.O4-Ba)
Asks for examples	Asks the student(s) to provide an example to illuminate the topic/ question/ problem/ phenomenon under study	**Ad.- Could you give an example of that? of two properties that increase together?** S1.- Eh…, the force and the acceleration. **Ad.- Ok, another one** that is not the one here? S1.- Eh… the mass and the acceleration? Ad.- Well, let's try to forget about second law. Use another property. I mean, time, temperature, whatever, money, results, etc. (E#9; Y9.O24-Ad)
Asks for justification	Asks the student(s) to justify her/another's ideas, reasoning, or the process or arriving at a solution	*Ch.– Now, Chase,* ***why do you think that this one is gonna melt quicker?*** *S3.- Because it doesn't feel cold, and it should in a way says it's warmer, it's because [inaudible] some heat on it. And… that's all, I don't know.* (E#4; Y10.O1.P-Ch)
Asks for keywords to build an explanation	Asks the student(s) to provide some keywords to build an explanation	*Ch.– That's the observation, yeah? 'The ice cube on the surface that feels colder melts quicker'. Ok? Why****? What are the key words here? What are the key words that we need to put into our explanation?*** *S1.– Energy.* *Ch.– Thermal energy, that's good. What else?* *S1.– Insulator.* *Ch.– Insulator.* *S2.– Conductor.* *Ch.– Ok.* (E#4; Y10.O1.P-Ch)

A.3.4. Inductive Codes for Discourse moves

CONTINUING MOVES	The teacher provides the means for the students to continue to elaborate either their own or their peers' reasoning	
Continuing: cluster codes	**Description: The teacher…**	**Example**
Asks for predictions	Asks the student(s) to make a prediction about a phenomenon	*Ch.– This one feels cold, this one doesn't feel cold. It's the only difference, really. Ok, well, this one was heavier, this one over here is lighter.* ***So, what do you reckon, guys?*** (E#4; Y10.O1.P-Ch)
Challenges degree of certainty	Ask questions to challenge student(s) degree of confidence in their answers	*Ba.- Can an insect do that?* *S8.- Yes.* ***Ba.- Which what percentage of confidence?*** ***S8.- 0%*** ***Ad.– Oh, wow! Let's see…, Angel?*** ***S9.- They do not regulate it. I'm 50% sure.*** (E#1; Y8.O1-Ba)
Checks agreement	Asks for student(s) agreement/ disagreement with a certain claim	Ad.- Ok, but it is the definition for a kind of material…what kind of material is it for? S1.- Elastic materials. **Ad.- Do you agree? Yes or no? Raise your hand before giving me an answer.**(E#2; Y9.O3-Ad)
Checks understanding	Ask questions to probe the status of student progress	*Al.- The strength depends on mass as well as distance. Then, it has more mass, the force is bigger. But it is further away, the force is smaller. Then, in that balance between mass and…, and distance, at that point it is in which it manages to rotate. if it were closer, maybe it would fall on the Sun. And if it were farther, maybe it would not turn around the Sun.* ***It is at the point where the force is in balance so that, with its speed, it can continue turning and neither escape nor fall, okay?*** (E#6; Y9.O6-Al)
Completes students' answers	Completes student(s) interventions with her own words	Ad.- Why did you said that when we were talking about throwing a ball, it will stop sooner if you throw it in the beach, I mean, in the sand, than if you throw it in a skate park? What's the different between both places? **S1.- That in a skate park, the…** **Ad.- The surface…** **S1.- The surface** is smooth, and in the beach, the surface is like the other way. Ad.- Yes, so, when we are talking about the force of friction, is it higher in the skate park, or in the beach? S1.- In the beach. Ad.- And that's because…. S1.- **Because it has more…** **Ad.- The key word is 'irregularities', ok?** so, we can say that if there are more irregularities, it is easier to be stopped; it is, it will be stopped sooner. if there are no irregularities, it will be stopped later, ok? (E#21; Y9.O32-Ad)

A.3.4. Inductive Codes for Discourse moves

CONTINUING MOVES	**The teacher provides the means for the students to continue to elaborate either their own or their peers' reasoning**	
Continuing: cluster codes	**Description: The teacher…**	**Example**
Direct instruction	Sets a new problem/question/activity/task and directly asks the student(s) to solve it	*Be.- Ok,* ***now we are going to try to look for information about this, to see if someone can help us clarify this****. With the help of your iPads, look for a hypothesis; it's a teamwork.* (E#3; Y9.O2-Be)
Completes students' questions	Completes student(s) questions with her own words	*S1.- If the Sun attracts the planets, and all that, and the Earth, the vector field ..., if you do so, the pen falls ... then,* ***why does the Sun not attract the Earth, like…?*** ***Al.- Why don't we crash into the Sun?*** *Because we have a speed. There is a speed. Remember when we saw the forces and saw the effects they could produce. One of them was the carousel with the swings. The carousel was spinning. And there was a force that pulled them towards the centre to always change their direction, right? Why doesn't that force make them crash into the central column of the carousel? Because they have a speed.* (E#7; Y9.O6-Al)
Convergent Questioning	Asks questions which typically have one correct answer	*Ch.– Air. And that's a mixture, isn't it? What's in the mixture, Caroline?* ***What gases are in the air?*** *S2.– Ahm, oxygen, …, ahm, can't remember.* *Ch.– No problem.* ***What is in there, apart from oxygen?*** *S3.– Nitrogen?* *Ch.– Nitrogen. More than 80. And a little bit of…* *S3.– Argon.* *Ch.– Argon! And then, a little tinnier bit of…* *S4.– Carbon dioxide.* *Ch.– Ok* (E#7; Y10.O2.P-Ch)
Convergent Questioning (giving options)	Asks questions which typically have one correct answer, giving the student(s) some options to facilitate the choice	*Ad.- Ok, how many steps are there between metres and cubic decimetres?* *S1.- One step.* *B.- Ok, you mean three zeros. (…)* ***So, are you going to multiply by 1000 and divide by 1, or are you going to divide by 1000 and multiply by 1?*** ***S1.- Eh…, multiply by 1000 and divide by 1.*** (E#1; Y9.O1-Ad)
Corrects the reasoning	Criticises/ Makes a comment and corrects an error in a reasoning process	Ad.- We said that they do not have dimension. **Why don't they have dimensions?** **S2.- Because they are dimensionless.** **Ad.- Okay, that's the same, but with another word.** But why is it dimensionless, or why does it have no dimensions? (E#26; Y11.O7-Ad)

A.3.4. Inductive Codes for Discourse moves

CONTINUING MOVES	The teacher provides the means for the students to continue to elaborate either their own or their peers' reasoning	
Continuing: cluster codes	**Description: The teacher…**	**Example**
Factual questioning	Poses questions that require fact-based answers.	Ch.–**Which was the less reactive?** S2.– The iron nail… Ch.–Ok, we all agree. What is the reaction between? **What is the iron reacting with?** S1.– Oxygen? Ch.– The iron is reacting with oxygen, good… and **where is the oxygen coming from?** S3.– The flame? Ch.– No! S1.– The air Ch.– Yes! It's coming from the air.
Invites elaboration	Probes/Asks the student(s) to elaborate for clarification/extension/example	*Be.- We said that water is made up of oxygen and hydrogen...so, why is it not a mixture that is made up of two things?* *S1.- Because it is formed by two elements.* *Be.-* ***And what else? What other condition must it have so that we can say that it is not a mixture but a compound?*** (E#5; Y9.O6-Be)
Invites reasoning	Poses a question to prompt student(s)' thinking	*S5.- Because if you crush it, it's all together and there are no air gaps.* *Be.-* ***And what consequences can this have?*** *S4.- That the thermometer would take the temperature of the air.* (E#2; Y9.O2-Be)
Poses chained questions	Poses a series of questions following a certain logic	*Ch.– Ahm… if I was holding a metal stick, yeah?, and one end of the metal stick is put into a very hot flame here, well,* ***what would happen to my hand?*** *S2.– It will get burnt.* *Ch.– I will get burn, all right?* ***Ok, so, what about this?*** *This piece of wood, ok? If I hold it in there,* ***what's gonna happen to my hand?*** *S2.– Nothing.* *Ch.– Nothing at all.* ***Why not?*** *S3.– The conduction… it's an insulator.* *Ch.* ***– What's an insulator?*** *The wood is an insulator.* (E#2; Y10.O1.P-Ch)
Poses closed questions	Poses questions that can only be answered by selecting from a limited number of options, usually 'yes' or 'no'.	*Ch.–* ***Are they soluble in water?*** *S2.– Yes.* *Ch.–* ***Are they the same solubility?*** *Ss.– No.* *Ch.– Which is more soluble?* *S2.– The blue. (E#14; Y8.O2.S-Ch)*

A.3.4. Inductive Codes for Discourse moves

CONTINUING MOVES	The teacher provides the means for the students to continue to elaborate either their own or their peers' reasoning	
Continuing: cluster codes	**Description: The teacher…**	**Example**
Poses guiding questions	Poses a question that encourages students to consider the information they have been taught, but to come up with their own answers.	*Ba.- What is the difference between whole wheat and non-whole or refined wheat?* *S1.- The whole is healthier.* *Ba.- **Yes, but the difference in the grain.** If you know why one is called 'whole' and the other is not.* *S1.- Well, the whole is like brownish.* *Ba.- Okay, yes, do you know why? **What has the whole wheat that the other does not have? Or rather, what does not have the other, the refined one...?** (…)* (E#5; Y8.O6-Ba)
Provides some prompts	Poses some questions/cues to facilitate dialogue	*Ad.- What makes ice more desirable as a surface for this sport?* *S1.- Because it is more slippery.* *Ad.- It is more slippery, **which is the same as saying that ...*** *S2.- It is more slithery.* *Ad.- It is more slithery, **which is the same as saying that ...*** *S3.- That it has less irregularities.* *Ad.- That it has less irregularities, **which is the same as saying that ...*** *S3.- That there is less friction.* *Ad.- That there is less friction, **that there is less...*** *S4.- Friction force.* (E#23; Y9.O33-Ad)
Provokes cognitive conflict	Tries to confront students with new information that contradicts their prior beliefs and ideas, then producing some mental discomfort	*Ch.– Pencil is made of graphite, isn't it? Not lead, it's graphite. **And it's insoluble. So, will it move with the water?*** *S1.– **No.*** *Ch.– **No! because it doesn't dissolve. No, these inks that are moving, what do you know about them? Are they soluble or are they insoluble?*** *S1.– **Insoluble.*** *Ch.– **So, they don't dissolve.*** *S1.– **Yes.*** *Ch.– **But, if they are insoluble, they will stay where they are.*** *S1.– **…They're soluble.*** *Ch.– **They're soluble because they are moving with the water, right?*** (E#14; Y8.O2.S-Ch)

A.3.4. Inductive Codes for Discourse moves

CONTINUING MOVES	The teacher provides the means for the students to continue to elaborate either their own or their peers' reasoning	
Continuing: cluster codes	**Description: The teacher…**	**Example**
Reasoning questioning	Poses a question that requires using reasoning skills in order to analyse and making sense of the physical world.	*S1.- Because they behave like a single body.* *Be.- **Why? Ok, I change the question.** Why does it take longer for the paper to fall than the book when they are separated?* *S2.- Because the book weighs more.* (E#15; Y11.O3-Be)
Reasoning questioning (restricted number of options)	Poses a question that requires using reasoning skills in order to analyse and making sense of the physical world.	*Ba.- In which time of the year are there more insects, Albert?* *S6.- During the spring.* ***Ba.- Why? There are two reasons.*** *S6. Because it is when the plants open.* *Ba.- Ok, plants do bloom in springtime, very good. And many insects eat flowers and eat pollen and nectar. **But there is another reason…, Andres?*** *S7. Because the eggs hatch?* *Ba.- The eggs hatch… the reproductive cycle of insects is organised in such a way that…* (E#1; Y8.O1-Ba)
Repeats (by rephrasing)	Repeats an idea proposed by a student in a slightly different way	***Al.- When we have a stone tied to a rope and we make it spin, what happens to the stone when it is released?*** ***S1.- That it goes off.*** ***Al.- It follows out in a straight line towards [inaudible].** If we release it when it's high, it will continue horizontally. Why? Because the velocity is tangent to the trajectory, OK?* (E#13; Y11.O11-Al)
Rephrases	States a student's utterance in a new or different way	*Ch.– What's the difference between the way the glass is expanding…?* *S1.– **It's slower.*** *Ch.– **So, it's expanding less, isn't it?*** (E#15; Y10.O2.P-Ch)
Rhetorical questioning	Uses a question/sequence of questions to emphasise or dramatise a point rather than to elicit an answer	*Ad.- Have you heard about the magnetic levitation train? It is basically a train, making it much simpler than it really is, in which there is a magnet below and another magnet above. What happens when we have two magnets?* *Ss.- They repel [each other].* *Ad.- They repel. **Well then, to a certain extent, this train, when it travels, does it without touching the tracks. Why is it so fast? Because there is no friction force. Because there is no contact surface. There is no frictional force with the tracks, but there is with the air**.* (E#23; Y9.O33-Ad)

A.3.4. Inductive Codes for Discourse moves

DISCOURSE MOVES	Description	
EXTENDING MOVES	**The teacher brings in new perspectives which expand the explanation-building process**	
Extending: cluster codes	**Description: The teacher…**	**Example**
Asks for an opinion	Asks the student(s) to express an opinion about a statement	*Ad.- "The acceleration that a force produces is inversely proportional to the mass of the body".* *S1.- I think it's true.* *Ad.- You think it's true, ok.* ***Any other opinion?*** (E#6; Y9.O19-Ad)
Asks for more contributions	Asks the student(s) to make a prediction about a phenomenon	*Ch.–* ***Anybody has something to add?*** *S1.– So, the energy is transferred along…* *Ch.– Yeah. So, it has to do with the vibration and the kinetic energy of the particles in the solid.* (E#2; Y10.O1.P-Ch)
Challenges degree of certainty	Challenges the student(s) confidence on their viewpoint	Be.- Why does it take longer for the paper to fall than the book when they are separated? S2.- Because the book weighs more. Be.- **Sure? Now let's make a ball with the paper. We drop them at the same time: 1, 2 and 3! Now, what**? S3.- They fall at the same time. (E#15; Y11.O3-Be)
Checks agreement/ disagreement	Asks whether students agree with another person's contribution	*Ch.– What do you think was being made? 10 seconds! 5 seconds, ok, hands up!* *S1.– Water?* *Ch.– Hands up if you agree with that. If you think it's water. We have 4 people who agree, ok. Now,* ***hands up if you disagree. Ok, you're very brave. Now, why do you disagree****?* (E#9; Y7.O2.S-Ch)
Ignores an answer and changes direction	Ignores an answer and changes direction	*Be.- And what is that?* *S7.-* ***The 'g'.*** ***Be.- Let's see. Why is it more dangerous to jump from the balcony of a fourth floor than jumping from the table?*** (E#16; Y11.O9-Be)
Ignores a student's intervention	Ignores a student's intervention	*Ba.- What do we have to do before the sowing?* *S1.- We have to stir the soil.* *Ba.- Why do we have to do that?* *S2. For it to aerate.* *S3. For it to oxygenate.* ***Ba.- For it to oxygenate, why?*** ***S4.- For plants to have enough nutrient.*** (E#2; Y8.O1-Ba)

A.3.4. Inductive Codes for Discourse moves

EXTENDING MOVES	The teacher brings in new perspectives which expand the explanation-building process	
Extending: cluster codes	**Description: The teacher…**	**Examples**
Ignores a wrong answer and provides the correct one	Ignores a student's intervention and provides his own answer	Ba.- Okay, yes, do you know why? What has the whole wheat that the other does not have? Or rather, what does not have the other, the refined one...? Who knows? **S2.- I do not know, but I think that the refined one has this sort of peel…** **Ba.- There is a layer (...). If you take the grain of wheat, it has a first layer, and in the refining process, it is removed, right?** That first layer is fibre, fundamentally. That is why it is said that the whole is very good for the digestive (E#5; Y8.O6-Ba)
Notes a misconception	States that one idea is a misconception and addresses it	*Ba.- But why do we have to oxygenate the soil? Through where do the plants take most of the material that will build them and make them grow from the little seed they were?* ***S5.- Trough the root****…, from the air, from the carbon dioxide…* ***Ba.- That's a very extended misconception, isn't it? "Plants are fed by the roots"; no. The plant…, most of the carbon that is used as building material for the plant comes from the CO2 that is around here.*** *What does it take from the root?* *Ss.- Nutrients.* (E#2; Y8.O1-Ba)
Offers an additional answer	Offers a pertinent contribution/ suggestion/ idea/ perspective/ information that makes the conversation progress in a certain direction	*S1.- In the question, it says: when do we say an object body is rigid? And the answer says: when it deforms… but if it's rigid, it does not deform, so…* ***Ad.- Ok, so, another example could be that if we are talking about this object, that you can imagine it is used as a hair band, if we apply a force, it changes its shape. If I stop [exerting] the force, it recovers its original position.*** *So, what kind of material is this?* *S2.- Elastic material.* (E#2; Y9.O1-Ad)
Provides examples	Provides examples to illustrate an idea/concept	*Ch.– Ok, all right. Yeah? So,* ***you've got the angels here****, and, at the moment, they are completely still, yes?, not a lot of movement. But* ***if we put a heat source under them, the air is being heated above the flame, which means that their particles are moving faster, which means they need to take more space, which means that area of air is less dense****. So, less areas move up, yeah?* (E#3; Y10.O1.P-Ch)
Repeats a statement and adds some information	Repeats a student's utterance adding some extra information to make the dialogue move on	*Ba.- Why these are not the ideal proportions?* ***S3.- Because there are mutations.*** ***Ba.- Because there are mutations****, we already know that there are. Or, maybe, it comes a bird who likes more white grains than yellow ones and eats them, I do not know. There are a lot of variables in nature that occur. What is done in science to counteract all these variables?* ***S4.- Do it many times.*** ***Ba.- Do it many times****. The more times, the more volume of data I have, the more I will approach the ideal proportions. (…)* (E#16; Y11.O5-Ba)

A.3.4. Inductive Codes for Discourse moves

EXTENDING MOVES	The teacher brings in new perspectives which expand the explanation-building process	
Extending: cluster codes	**Description: The teacher…**	**Examples**
Repeats with an interrogative tone	Repeats a student's utterance using an interrogative tone to show disagreement or to make the student rethink their intervention.	*Ba.- How would you explain that? I'm always going to ask you why you think that data are like that. This is a tendency that always occurs ... what do you think can be attributed to the fact that there are more deaths each year?* ***S1.- To drugs.*** ***Ba.-To drugs?*** *Do you think that there are more drugs year by year?* *S1.-No, but every year [people] hook on earlier.* *S2.- Or because every year* ***there are more drunkards that take the car ...*** ***Ba.- But are there more and more drunkards?*** *That is not… what re you based on? On the contrary, the government proposes progressively more measures, and we are progressively more aware of many things that happen... then, why is there this increase?* ***S3.-Well, maybe because of a big fire ... in a fire people can die ...*** ***Ba.- Is there a super fire every year?*** *(…)* (E#8; Y10.O3-Ba)
Rephrases and adds information	States a student's utterance in a new or different way and adds some information	*Ch.– There's something else with temperature that has a much bigger effect than just increasing the number of collisions.* *S1.– I'm not sure, but, because there's more temperature, they have more energy to pass… so, because to make collisions successful for the reaction there has to be a certain amount of energy…* *Ch.–* ***Ok, let's talk about this again, right?*** *So, if they miss each other, there is no chance of reaction. If they hit each other with not enough energy, they don't react. But if they hit with enough energy, they will react. (E#10; Y10.O3.C-Ch)*
Rhetorical questioning	Uses a question/sequence of questions to emphasise or dramatize a point rather than to elicit an answer	*S2.- It was an epidemic. The 1918 influenza pandemic.* ***Ba.- What is a pandemic? A huge epidemic which affects a large part of the world's population; it is not local.*** *This epidemic was called 'the Spanish flu' because, as she says, many countries were at war and in Spain there was more freedom of information, in the newspapers, then they published it. But it is not that more people died in Spain*. (E#13; Y10.O4-Ba)
Sets a new topic/ perspective	Introduces a new perspective into the dialogue	Ba.- And what does that originate? S4.- That there may be tomato at all times of the year. **Ba.- And now, if we talk about responsible consumption, what information should we have so that our way of consuming food is the least harmful to the land or to the environment?** How does that affect, Arantxa? S5.- We should know when the season of each thing is. Because many times they are not planted in other countries, but they change their DNA, or with chemical products to help [the plants] grow, but it's always going to be better to eat them from your garden. (E#6; Y8.O8-Ba)

A.3.4. Inductive Codes for Discourse moves

DISCOURSE MOVES	Description	
REFERRING MOVES	**The teacher refers to some shared knowledge**	
Referring: cluster codes	**Description: The teacher...**	**Examples**
A future topic	Makes mention to a topic that will be introduce in the future	*Al.- It follows out in a straight line towards [inaudible]. If we release it when it's high, it will continue horizontally. Why? Because the velocity is tangent to the trajectory, OK? So, how is it possible for bodies to turn? Because there is something that forces them all the time to change the address, okay?* ***In general, there is a force. Since the topic on forces is the next one in the syllabus, for now, we are going to say that there is an acceleration, okay?*** *Well, this acceleration, what it does, is to change the direction of the velocity vector all the time. And it always points to the centre.* ***It is called 'normal acceleration' or 'centripetal acceleration'. Centripetal because it points to the centre****.* (E#13; Y11.O11-Al)
Practical aspects of science	Makes mention to some practical aspect of the scientific enterprise	*Al.- There's no n here, right?* [referring to the y-intercept] W*hy? Because more or less, it has to be zero. And almost everyone got that. You have obtained 'zero, comma, zero something, zero, zero, zero something', okay?* ***That in experimental measurements is normal. That is close to what it has to be, even if it's not exactly. Because everything has its error.*** *We were measuring with springs; besides, we were outside, we were not in the lab, that also makes you more distracted ... anyway.* (E#2; Y9.O2-Al)
Prior activities /situations	Refers back to activities or situations that have been performed in the past	*Be.-* ***Do you remember when we went out to the playground and we did the activity of 'I am a solid', that we did not move****? Well, for that energy, my group's companions have bothered me so much that in the end what I want is to move, and I become a liquid.* (E#3; Y9.O2-Be)
Prior contributions	Refers back to ideas which have already emerged in the flow of discourse	*Ch.– Ok,* ***Chris has told us why, I hope you all listened. But, please, Chris, tell us one more time.*** *S1.– Yes. Conduction doesn't work very well in liquids. – perfect.* (E#5; Y10.O1.P-Ch)
Prior explications	Refers back to a previous explication	*Al.- Why don't we crash into the Sun? Because we have a speed. There is a speed.* ***Remember when we saw the forces and saw the effects they could produce. One of them was the carousel with the swings.*** *The carousel was spinning. And there was a force that pulled them towards the centre to always change their direction, right? Why doesn't that force make them crash into the central column of the carousel? Because they have a speed.* (E#7; Y9.O6-Al)

A.3.4. Inductive Codes for Discourse moves

REFERRING MOVES	The teacher refers to some shared knowledge	
Referring: cluster codes	**Description: The teacher...**	**Examples**
Prior knowledge	Refers back to some knowledge that the students have acquired in the past	*Al.- The strength depends on the masses and the distance. And you are seeing that distance is also important. Because, in fact, it's true, the Sun is much bigger than the Earth. And it exerts a gravity on the Moon. But as the Moon is closer to the Earth, it is the action of Earth's gravity that prevails in that movement.* ***In fact, the tides… have you studied the tides yet?*** ***S3.- Yes, last year.*** ***Al.- Why are the tides produced?*** ***S4.- By the Moon.*** *Al.- By the Moon's gravity, right? But by the gravity of the Sun too. Do you know that there are spring tides and neap tides?* *Ss.- No.* *Al.- They are all tides, but we call 'spring' to those which are very strong. That is to say, there are many meters of difference between the low tide and the high tide, and the neap tides are those in which there are less differences. Why does that exist? Because when just the gravity of the Sun and the gravity of the Moon pull towards the same place, the tide is a spring tide. That is, the Sun's gravity acts on the body of water. The Moon has more influence for being closer, but the Sun too, because it is very big, okay?* (E#6; Y9.O6-Al)
Students' reality	Establishes a connection with students' daily life	*S3.- For example, with regard to suicide, as in adolescence you are more affected by the comments of people of your same age, maybe what they say affects you in another way, in an exaggerated way, and that takes you to suicide.* *Ba.- It might make sense, because we have seen that one of the functions of the frontal lobe, which is the one that takes longer to develop... do you remember what its function is?* *S4. Planning and problem solving.* ***Ba.- This is very important, because at your age the problems are the biggest in the universe, and then you realise that they are not so big. And that could be related to the way in which one faces the problems that arise in one's life. At your age it is not fully developed to undertake this****... it makes sense, although I do not know if it is related to this.* (E#10; Y10.O4-Ba)

A.3.4. Inductive Codes for Discourse moves

DISCOURSE MOVES	Description	
REPLYING MOVES	**The teacher provides responses to explicit questions**	
Replying: cluster codes	**Description: The teacher...**	**Examples**
Admits ignorance	Recognises not to know an answer	*S1. – Why is ammonia so bad smelly?* *Ch.–* ***I don't know that answer****. Obviously, it is interacting, isn't it? With your..., your sensory glands in your nose, in that area****… I have no idea, no idea. The whole science of smell is a mystery to me, to be honest with you****.* (E#16; Y10.O3.C-Ch
Refuses to answer a question/go deeper	Decides not to answer a student's question/delve into a student's expressed topic of interest	*S2.- And what if there are two suns?* *Al.- What if there are two suns? Oh, my God, I do not know! Well, if there were two suns, then maybe we would be 8, or ... I do not know.* ***I do not know, but if you are interested, you can continue studying on your own****.* (E#6; Y9.O6-Al)
Responds to a doubt with a question	Replies to a doubt posed by a student with a question	***S1.- But I do not understand it; because, for example, Jupiter is much bigger than Earth, then, it should be closer to the Sun.*** ***Al.- Uh, no. Why?*** *S1.- Because… because it has more mass, then, it is more strongly attracted.* *Al.- Yes. But it's farther. The strength depends on mass as well as distance*. (E#6; Y9.O6-Al)
Responds to explicit comments	Responds to a comment uttered by a student	*Be.- The water is denser, so…* *S1.-* ***But the egg weighs more!*** ***Be.- But here we are not talking about weight, but about density****.* (E#13; Y11.O1-Be)
Responds to explicit questions	Responds to a question launched by a student	*Ad.- Well then, to a certain extent, this train, when it travels, does it without touching the tracks. Why is it so fast? Because there is no friction force. Because there is no contact surface. There is no frictional force with the tracks, but there is with the air (...).* ***S1.- But what if it fails?*** ***Ad.- If it fails, it cannot advance. As if a normal train is damaged.*** ***S1.- Ok, but if, for example, one of the two magnets fail? It does like this [gesticulating] and you've been killed.*** ***Ad.- No, come on, don't be so dramatic! The only thing that happens is that the magnets are no longer separated and are resting on the track. And if it is stopped, it does not run. Nothing more happens than that.*** ***S1.- But do are not killed?*** ***Ad.- No, you are not killed****.* (E#24; Y9.O33-Ad)

A.3.4. Inductive Codes for Discourse moves

DISCOURSE MOVES	Description	
COMMENTING/ REINFORCING MOVES	**The teacher utters some statements in the course of discourse to give personal remarks or evaluations of the situation**	
Commenting/Reinforcing: cluster codes	**Description: The teacher...**	**Examples**
Adds some information and makes a reinforcing statement	Adds information to a student's utterance and makes a reinforcing statement	*Al.- Although we put a hand very close, very close to a pen, and we have a mass, and the pen has another mass, we are not able to attract it, right?* *S1.- That would be awesome.* *Al.- Yes, but that's not the case; why? Because, even though it seems to us that the masses are very large and the forces are very large, it is really a weak force. That is why it occurs between very, very, very large masses.* ***Do you know what the mass of the Earth is?*** ***S2.- A lot.*** ***Al.- Of the order of 10 to 24 kg. A lot, indeed.*** (E#5; Y9.O5-Al)
Explicitly shows agreement	Shows explicit agreement with a student's idea/ contribution/answer	*Ad.-* ***Ok, we agree about that. I mean, we know that it's easier to move a light object than a heavy one****. But now, we have to demonstrate that information using numbers, ok?* (E#7; Y9.O19-Ad)
Makes a challenging remark	Challenge students to participate	*Can anyone describe how is the conduction process happening?* ***Anyone be brave and have a go!*** *Claude. (E#2; Y10.O1.P-Ch)*
Makes a positive/ motivational/encouraging statement	Provides encouragement or motivation for students	*Ch.– What makes you think that's a good answer?* *S1.– Water is one of the only neutral substances.* *Ch.–* ***Great answer! Very good, that's excellent****.* *S2.– Because if you have water you need hydrogen, which is H, and Hydroxide, which is HO, which is what makes something acid and what make something alkali… so, if you add and acid to an alkali to make it neutral, then, the H and the HO combine in H2O.* *Ch.–* ***That is a great answer. That's a fantastic answer****. He knows that water is H2O, he knows that acids got H, he knows Hydroxide is OH. If you put H and OH together, you get H2O. that's a great answer.* ***Very, very good****.* (E#9; Y9.O1.C-Ch)

A.3.4. Inductive Codes for Discourse moves

COMMENTING/ REINFORCING MOVES	**The teacher utters some statements in the course of discourse to give personal remarks or evaluations of the situation**	
Commenting/Reinforcing: cluster codes	**Description: The teacher...**	**Examples**
Recognises the value of an intervention	Highlight the value of a student's intervention	*Ba.- (…) Why do you think life expectancy is those countries are those?* *S6.- Well, from my point of view, and from what I have researched, these differences are due to the food of each country and the diets people follow. Because, for example, the Internet shows that the diet of the Japanese is very good.* *Ba.- One of the factors that makes it so is the type of food. Something that one can modify at will.* ***This is very important****.* (E#12; Y10.O4-Ba)
Repeats (adding some information)	Repeats a student's utterance adding some extra information	*Be.- And the gas particles, how did they move?* *SS.-* ***In 3-D.*** ***Be.- In 3-D, very well, and occupying all the possible space****. (E#2; Y11.O2-Be)*
Shows agreement	States her agreement with the idea or statement of some student	*S6.- And, of course, the health system of each country, since, if there is any disease, you must have the medication or the treatment to cure it.* ***Ba.- Totally true.*** *The health system has a great effect on death rates. And fortunately, in Spain we also have a good health system, always improvable, and above all that, until now, it has been public, which is something that we also hardly value, but when you go to other places you realise how important it is to have a public health system that takes care of anyone when something happens.* (E#12; Y10.O4-Ba)
DISCOURSE MOVES	**Description**	
CONCLUDING MOVES	**The teacher closes the explanation-building process**	
Concluding: cluster codes	**Description: The teacher...**	**Examples**
Adds some information	Concludes the explanatory episode by adding information to a student's utterance	*Ad.- The one with the floor, ok?* ***So, if you want to go faster, it is better not to have friction. If we want to be safer, it is better to have friction.*** (E#21; Y9.O31-Ad)

A.3.4. Inductive Codes for Discourse moves

CONCLUDING MOVES	The teacher closes the explanation-building process	
Concluding: cluster codes	**Description: The teacher...**	**Example**
Changes of topic	Concludes the episode by changing the topic	*Ad.- You do know that the gravity on the moon is not the same as on Earth.* *S1.- Because there is no oxygen?* *Ad.- It has nothing to do with it, we'll see that. It is rather the other way around: there is less oxygen because there is less gravity, okay?* ***But well, in any case, without entering into the composition of the atmosphere,*** *we are saying that the force that we are considering, sometimes is called 'gravity' and other times is called 'weight'. (E#17; Y9.O30-Ad)*
Checks understanding	Concludes the episode by gauging students' understanding	Ad.- The weight is going to change. Why? What is changing in order to say that the weight changes? [silence]. (…) What is the only property that you can change? The gravity of the planet. **Is that clear?** (E#13; Y9.O28-Ad)
Checks understanding and summarises	Concludes the episode by gauging students' understanding and summarising the main information/ idea	*Ch.– So, what we're talking about is separating thing that are less or more soluble.* ***Fair enough?*** *S1.– Yes.* *Ch.–* ***So, that's why it's a separating technique. You are separating here certain parts of the ink that are more soluble than others. Make sense? You can use it to identify things****.* (E#14; Y8.O2.S-Ch)
Does not give a final answer	Leaves the episode open	Be.- *When making a ball with the paper, has its weight changed?* Ss.- *No.* Be.- *But now they have fallen at the same time…* ***curious… ok, sit down.*** (E#15; Y11.O3-Be)
Does not give a final answer (but this will be given in the future)	Leaves the episode open but says they will conclude it in the future	*Ad.- Do you think that's because of the weight of because of the mass? Or because both of them?* *S1.- Both of them.* *Ad.- Ok,* ***that's a question we are going to try to answer in a few minutes****.* (E#4; Y9.O9-Ad)
Gets back to the main topic	Concludes the episode by getting back to the main topic/question	*Al.- They are all tides, but we call 'spring' to those which are very strong. That is to say, there are many meters of difference between the low tide and the high tide, and the neap tides are those in which there are less differences. Why does that exist? Because when just the gravity of the Sun and the gravity of the Moon pull towards the same place, the tide is a spring tide. That is, the Sun's gravity acts on the body of water.* ***The Moon has more influence for being closer, but the Sun too, because it is very big, okay? OK, I'm interested in here that you have the idea, the concept of field, very clear*** (E#6; Y9.O6-Al)
Makes an evaluative comment	Concludes the episode by making an evaluative comment about an answer given by a student	*Ad.- Ok. So that's your result. It is expressed in decimal notation. What about the scientific notation, is it correct, or not? What do you think?* ***Yes, it is correct.*** (E#1; Y9.O1-Ad)

A.3.4. Inductive Codes for Discourse moves

CONCLUDING MOVES	The teacher closes the explanation-building process	
Concluding: cluster codes	**Description: The teacher...**	**Example**
Introduces a new a term	Concludes the episode by introducing a new a term	*Al.- If we release it when it's high, it will continue horizontally. Why? Because the velocity is tangent to the trajectory, OK? So, how is it possible for bodies to turn? Because there is something that forces them all the time to change the address, okay? In general, there is a force. Since the topic on forces is the next one in the syllabus, for now, we are going to say that there is an acceleration, okay? Well, this acceleration, what it does, is to change the direction of the velocity vector all the time. And it always points to the centre.* ***It is called 'normal acceleration' or 'centripetal acceleration'. Centripetal because it points to the centre****.* (E#13; Y11.O11-Al)
Introduces a subsequent activity	Concludes the episode by telling the students what they will do next	Ch.– Ok. Well, **we've got a short video to watch, and you are going to make predictions in the middle of this video. And then, they'll show us an experiment, and you can see if you were wrong or right**. Ok, it's a video about conduction, well, not really specifically conduction, it's more to do with insulation. (E#3. Y10.O1.P-Ch)
Provides a conclusive answer	Explicitly concludes the episode by with a statement	*S1.- Let's see, miss. The Sun burns atoms to keep on burning. If it has already been billions of years burning, why doesn't it turn off?* *Al.- Because…, it's a bit complicated for you to understand, but basically because, although it's true that it's a big ball of He, H…* *S1.- Wouldn't they burn completely and that's all?* *Al.- No, because, they burn, well, they burn ..., it is that for you to burn is to being destroyed.* ***S1.- And when is it going to turn off?*** ***Al.- It's going to turn off, but I do not know if we know. Well, within millions of years****.* (E#8; Y9.O6-Al).
Provides correct/predetermined answer	Concludes the episode by providing a correct/predetermined answer	*Ch.– Not pretty sure about it, ok.* ***This is what it happens in reality****. The diameter of this one is much bigger. Just imagine it is the same size. So, overall, the expansion is, let's say, 2mm3, right? 2mm3 in a thin tube is a big difference, whereas in the big one, is not. So, here, you will have to have 20, 21, 22, 23… that will be the difference between 20 and 37, whereas here, you could have that as the difference between 20 and 37. And you can have a lot more spaces and, as L. said, it would be more accurate, wouldn't it? Makes sense?* (E#15; Y10.O2.P-Ch)
Provides time for explanation improvement	Gives the students some time to complete/improve a written answer	Ch.– Now, having listened to someone else's, is there any way you think you could improve yours? Something you could add to yours? You've got one minute to add something that, after listened someone else's explanation, you say 'Oh, I like that!', or 'I wanna use that word'. **You've got one minute to improve your explanations**. (E#4; Y10.O1.P-Ch)

A.3.4. Inductive Codes for Discourse moves

CONCLUDING MOVES	**The teacher closes the explanation-building process**	
Concluding: cluster codes	**Description: The teacher...**	**Example**
Reaches certain agreement	Concludes the episode after having achieved certain agreement	Be.- *Ok.* ***I already think that more or less everyone is in this****. The objects do not fall with constant speed; they fall accelerating.* (E#16; Y11.O9-Be)
Recognises his ignorance	Concludes the episode by admitting he/she does not know the answer to a students' question	*S1.- Why do the snails go out when it rains?* *S2.- Because they are sluggish and crawl through the water.* ***Ba.- Well I do not know exactly; I should think about it.*** (E#3; Y8.O1-Ba)
Refers back to the opening question	Concludes the episode by referring to the opening question	*Ba.-* ***Why are there more birds that eat our vegetables during the winter?*** (…) Ba.- ***That's why this is the worst time for [having] plagues of birds that eat our leaves****. That's why we have to put plastic bottles to cover our plants, because the birds look for food. Your spines, the well-being of each one of the plants on your spines is an assessable dimension, so that each one here has to manage them so that the bird does not eat his/her plants. And there are people who have plants that birds like a lot, and others who have onions or garlic, bad luck.* (E#1; Y8.O1-Ba)
Refers to a different area of knowledge	Concludes the episode by connecting to a different area of knowledge	*Al.- I'm interested in here that you have the idea, the concept of 'field', very clear. The field, which is the action that the masses suffer, in this case because it is a force between masses, around another that exercises that field. Since it is a field with arrows, that is, with vectors, it is called 'vector field'.* ***That is studied in mathematics at much higher levels. But you know that these vectors are studied mathematically, with numbers and so on.*** (E#6; Y9.O6-Al)
Refers to a real situation/reality	Concludes the episode by referring to real conditions	*Ad.- In the cases we are analysing, it is assumed that the bodies do not have friction. If there were no friction, as the mass is the same, the acceleration of gravity is also the same, and, consequently, the two would fall at exactly the same speed.* ***What happens is that this is an ideal theoretical framework. And we know that practical reality is a little different. But that does not mean that this is not true. What it means is that we are changing the conditions****. (E#25; Y11.O1-Ad)*
Refers to sociological aspects of science	Concludes the episode by referring to sociological dimensions of the scientific enterprise	*S1.- But inside a black hole, time does not pass, nor anything, right?* *Al.- Yes, sure! It captures everything.* ***I'm sorry to tell you that your physics and chemistry teacher does not know everything. Partly because of my ignorance and partly, because we do not know everything. That is why there is the R + D + I, to continue researching****.* (E#9; Y9.O6-Al)
Refers to the future	Concludes the episode by referring to a future topic	*Be.- But here we are not talking about weight, but about density.* ***We'll do this again when we are in the topic of hydrostatics.*** (E#13; Y11.O1-Be)

A.3.4. Inductive Codes for Discourse moves

CONCLUDING MOVES	**The teacher closes the explanation-building process**	
Concluding: cluster codes	**Description: The teacher...**	**Example**
Refuses to answer a question	Refuses to answer a students' question not related to the topic	*S1.- But inside a black hole, time does not pass, nor anything, right?* *Al.- Yes, sure! It captures everything. I'm sorry to tell you that your physics and chemistry teacher does not know everything. Partly because of my ignorance and partly, because we do not know everything. That is why there is the R + D + I, to continue researching.* ***Ok, another question. Is it about black holes or about springs?*** ***S2.- Black holes.*** ***Al.- Then, no****.* (E#9; Y9.O6-Al)
Remarks a misconception	Concludes the episode by addressing a misconception	***Ba.- That's a very extended misconception, isn't it? "Plants are fed by the roots"; no.*** *The plant…, most of the carbon that is used as building material for the plant comes from the CO2 that is around here. What does it take from the root?* *Ss.- Nutrients.* *A.- Minerals and nutrients,* ***but not most of the material that constitutes it, right?*** (E#2; Y8.O1-Ba)
Remarks the purpose of the activity	Concludes the episode by remarking what (s)he expected from the activity	*Ba.- (…) Can anyone give me an explanation for the second descent?* *S3.-The Spanish civil war.* *Ba.- Wars kill people.* ***Notice that the data is telling me part of the history of a country. I can know things about a country by researching only numbers. This is based only on numbers of deaths. Look at the amount of information a single datum can provide*** (E#13; Y10.O4-Ba)
Repeats and makes a confirming comment	Repeats a student's utterance and makes a confirming comment to reinforce the conclusion	Ad.- Why has my speed changed? What have they done to me when they pushed me? S1.- Apply a force. Ad.- They have applied a force to me. And, since I have a mass, applying a force is the same as granting me one ... S2.- Acceleration. **Ad.- Acceleration, indeed!** (E#8; Y9.O21-Ad)
Repeats the last idea and adds some information	Repeats a student's utterance and adds some extra information to conclude	***S4.- More people die every year because there are more and more people.*** ***Ba.-That's it! There are more and more people in Spain, that's why more and more people die every time.*** *In fact, we are in a stage of exponential growth of the human population. Do you know how many inhabitants there are on the planet, more or less? Between 7,000 and 8,000 million, very well. (E#8; Y10.O3-Ba)*

A.3.4. Inductive Codes for Discourse moves

CONCLUDING MOVES	**The teacher closes the explanation-building process**	
Concluding: cluster codes	**Description: The teacher...**	**Example**
Rephrases a student's contribution and makes a positive statement	Rephrases a student's contribution and makes a positive statement to conclude	*Ch.– That is a great answer. That's a fantastic answer.* ***He knows that water is H2O, he knows that acids got H, he knows Hydroxide is OH. If you put H and OH together, you get H2O. That's a great answer. Very, very good***. (E#9; Y9.O1.C-Ch)
Rephrases the last idea and adds some information	Summarises (selected) ideas, highlights particular [concepts] of importance, and/or points to next steps related to the summary	***Ba.- They lose property for sure.*** *We can verify this. (…)****That makes it lose property, the tomato, for the fact of being ... okay? Because keep in mind that it is a plant, which is connected to the vascular system of the plant, and that water is reaching it, and a series of nutrients are arriving. At the moment that you pull it up, nothing comes of that. In fact, there comes a time that it rots. That is an argument***. (E#6; Y8.O8-Ba)
Rephrases the last intervention to conclude	Rephrases the last intervention to conclude the episode	Ba.- Motivated by…? Those physical changes in women, why do they occur? For an increase in sex hormones, in this case. And what's the final sense of it? **S6.- For the birth canal.** **Ba.- Well, she is being prepared to become a mom**. (E#7; Y10.O1-Ba)
Summarises (and adds some information)	Summarises (selected) ideas and adds some extra information	*Be.- [I]f we have the supersaturated [solution] and it is cooled down, what will happen?* *S2.- It separates.* *Be.-* ***All that did not fit at that temperature precipitates again to the bottom. That is why the solubility had to be defined with respect to a certain temperature***. (E#12; Y11.O1-Be)
Summarises (by naming a concept/idea)	Summarises (selected) ideas by giving them a technical name	*Ch.– So, the heat is not travelling, or at least, it is not travelling very well, ok? All right****.*** ***That was a bit of revision about conduction***. (E#2; Y10.O1.P-Ch)
Summarises (by repeating)	Summarises (selected) ideas by repeating the last utterance	*Be.- In 3-D, very well, and occupying all the possible space.* ***That is, the temperature remains constant because the energy we give to it is not spent in raising the temperature, but in changing the order of the particles, so they move from one state to another state***. (E#3; Y9.O2-Be)
Summarises (by rephrasing)	Summarises (selected) ideas by stating it in a different way	*Be.- And what consequences can this have?* *S4.- That the thermometer would take the temperature of the air.* *Be.-* ***We crush to have a homogeneous substance, so that what we measure is more real***. (E#2; Y9.O2-Be)

A.3.5. Inductive Codes for Instructional Activities

TYPE OF ACTIVITY	DEFINITION
Task/Activity/Exercise checking/correction/assessment	Elicitation of the process followed to find the solution of a task
Didactic (instructional explication)	Teacher-centred method of knowledge transmission
Thought experiment	Device of the imagination performed to speculate within a specifiable problem domain, about potential solutions
Modelled experiment	Hands-on activity performed by the teacher in front of the students
Whole-class experiment	Hands-on activity performed by all the students (and the teacher) at the same time
Student experiment (in pairs)	Hands-on activity performed by students who work in pairs
Student experiment (individually)	Hands-on activity performed by individual students
Whole-class dialogue	Discussion shared with all members of the class
Cooperative activity	Classroom activity in which students work together to solve a problem
Oral presentation	Presentation of conclusions performed by a student
Book-based activity (with pair/whole class discussion)	Activity based on a textbook
Pair discussion	Discussion hold by two students (with/without teacher's guidance/prompting)
Teacher demonstration (with questioning)	Activity performed by the teacher to communicate an idea with the aid of visuals
Explanation writing	Written activity in which students are asked to explain an observed phenomenon

A.3.6. Inductive Codes for Patterns of Interaction

PATTERN OF INTERACTION	DEFINITION
IRF sequences	Three-part exchange structure consisting in the initiation of the dialogue by the teacher (I), normally with a question; R is the student's response, and F is the feedback from the teacher.
IRE(F)P complex sequences	Three-part exchange structure consisting in the initiation of the dialogue by the teacher (I), normally with a question, followed by a student's response (R), which is evaluated by the teacher. The teacher can also provide some feedback. To conclude, he/she gives a prompt, which may initiate a new sequence.
Student interventions sequences	Various students intervene in the conversation alternating their interventions
Teacher's question – teacher's answer	The teacher poses a question and he/she answers it

Student's question – Teacher's answer	A student poses a question and the teacher answers it
Student's intervention without being interrogated	A student makes a statement/answers a question without having been addresses by the teacher
Interruptions	Someone interrupts any other person's discourse
Hesitations and pauses	The speaker hesitates and/or introduces pauses in his/her speech
Alternation with interruptions	Someone interrupts any other person's discourse
Group sharing	Students share their conclusions/solutions/results with the whole class
Out loud reading	Students read a fragment form a textbook aloud
Student-student interaction	Students interact with each other (e.g., by posing questions and answering them)

A.3.7. Preliminary Codes for Assessment

	DEFINITION
TYPES OF ASSESSMENT	Each type of assessment serves a different purpose and is linked to a stage of instruction
Diagnostic	Pre-assessment: is done by the teacher before the instruction to determine students' knowledge, attitudes and interests, strengths and weaknesses. This information is then used as a starting point to make decisions about instruction (Burden and Byrd, 2013, p. 284)
Formative	It occurs during instruction and is a way to assess students' progress, provide students with feedback, and assist the teacher in making decisions about further instruction (Burden and Byrd, 2013, p. 284)
Summative	It occurs after instruction (the end of a unit, marking period or course) and it serves as a means to document what students know, understand and can do (Burden and Byrd, 2013, p. 284-285)
ASSESSMENTS METHODS	Teachers' knowledge of methods of assessment includes knowledge of specific instruments or procedures, approaches or activities that can be used during a particular unit of study to assess important dimensions of science learning, as well as the advantages and disadvantages associated with employing a particular assessment device or technique.
Written test on content	The student must answer questions about factual knowledge
Oral presentation	Students are asked to prepare a report on a selected topic and then present it to the rest of the class (Burden and Byrd, 2013, p. 292)
Paper essay	The student must compose a response to a question for which no single answer can be cited as correct to the exclusion of all others (Borich, 2011, p. 403)
Classroom debate	A group of students or the entire class is involved in an activity in which students exhibit certain knowledge and skills through their participation (Burden and Byrd, 2013, p. 292)

Portfolio	Planned collection of materials that documents what a student has accomplished and what steps he/she took to get there. It includes journal entries, written laboratory reports, and artefacts such as drawings, working models, or multi-media documents (Borich, 2011, p. 420).
Observation of group work	During group work (pairs/small groups/whole class), the students collaborate to learn by interacting dialogically with each other. The teacher observes how the students handle themselves within this social dynamic
DIMENSIONS TO ASSESS	Set of characteristics or aspects that teacher believes should be considered in evaluating the learning process

A.4. SCHEDULE FOR THE SEMI-STRUCTURED INTERVIEW

TOPIC OF INTEREST	POSSIBLE QUESTIONS
ESTABLISHING THE INTERVIEW SETTING	(Describe the purpose and format of the interview) (Start by recording date, time, and participant's name)
UNDERSTANDING TEACHER'S CONTEXT	1. Where do you work? 2. How would you describe your workplace? What characteristics would you highlight about it? 3. What is your School's environment like? How do you think it affects the dynamic of your work? 4. How long have you been working in this School? 5. And how long have you been working as a teacher? 6. What subjects do you teach? 7. At which level?
UNDERSTANDING TEACHER'S IDENTITY	8. How would you characterise yourself as a teacher? I mean, what would you highlight of your way of teaching or what do you see as your teaching strengths? 9. What is the thing you enjoy the most when teaching science? 10. What areas do you feel are relatively weak in your teaching? /Is there any professional aspect that you would like to improve? 11. How do you prepare to teach something that is new to you? 12. What would you say is it the most important thing you can teach your students? 13. And regarding the subjects you teach? I mean, what do you want your students to *take away* from their learning experiences with your science classes? 14. What should be the roles of students and teachers in the science classroom? 15. In your opinion, what are the most important qualities that a science teacher should have in teaching science?
TEACHER'S IDEAS ABOUT SCIENCE	16. What is 'Science' for you? 17. What do you think are the general aims or objectives of science? I mean, what is science for? 18. Do you think that your way of understanding science influences the way you teach? In what sense?

TEACHER'S IDEAS ABOUT SCIENTIFIC EXPLANATION	19. How would you define 'explanation'? And 'scientific explanation'? 20. What elements do you think a good scientific explanation should include?
REFLECTIONS ABOUT THE INSTRUCTION OF SCIENTIFIC EXPLANATION (PCK)	24. Have you ever asked yourself this kind of questions about explanations? 25. During your training programme to become a science teacher, did anyone explicitly address this issue? 26. Do you think it is important for teachers to receive more information and guidance about how to support students in the construction and evaluation of scientific explanations? 27. What would you intend the students to learn about scientific explanation (*)? 28. Do you find it important for students to know this? Why? (*) 29. What difficulties/limitations do you consider that are connected with teaching this scientific practice? (*)
TEACHER'S EXPLANATION-BASED KNOWLEDGE AND PRACTICES	30. Do you explicitly address the construction of scientific explanations in your science lessons? 1. IF 'YES' → How? 2. IF 'NO' → Why not?
CHANGE AND TEACHING PRACTICES (Not included)	34. There are some educational researchers who say that there is an imbalance between what is required of science teachers, what is taught to them in their training programmes and what they actually put into practice in their classrooms... to what extent do you agree with this statement? 35. If you considered that you are in that situation, what would you do to change it? Have you ever had that feeling? 36. Do you think it is easy for a teacher to change the way he/she understands teaching? And for you? 37. What do you think it would be necessary to promote change?

(*): Adapted from Loughran *et al.* (2001; 2004).

A.5. EXPLANATION-BUILDING EPISODES IN ADRIAN'S LESSONS.

EPISODE 1 (E#1; Y9.O1-Ad).

*Ad.- **Could you explain what you have done?***
S1.- First, I do decimal notation.
Ad.- Ok.
S1.- Then, I apply the conversion factor.
Ad.- Ok, how many steps are there between metres and cubic decimetres?
S1.- One step.
Ad.- Ok, you mean three zeros. (…) So, are you going to multiply by 1000 and divide by 1, or are you going to divide by 1000 and multiply by 1?
S1.- Eh…, multiply by 1000 and divide by 1.
Ad.- Ok. So that's your result. It is expressed in decimal notation.

EPISODE 2 (E#2; Y9.O1-Ad).

Ad.- Ok, the question is 'when do we say a body is rigid?' So, ***I want you to tell me if the first answer is correct or not, and the reasons why you have made that decision****. Raise your hand before talking, please. (…).*
S1.- In the question, it says: when do we say an object body is rigid? And the answer says: when it deforms… but if it's rigid, it does not deform, so…
Ad.- Ok, so, another example could be that if we are talking about this object, that you can imagine it is used as a hair band, if we apply a force, it changes its shape. If I stop [exerting] the force, it recovers its original position. So, what kind of material is this?
S2.- Elastic material.
Ad.- It's an elastic one. So, this definition is for elastic materials. So, I want you to tell me that this is false just because it's the definition for an elastic material. So, 'A' is not the correct answer.

EPISODE 3 (E#3; Y9.O3-Ad).

Ad.- Is 'A' the correct [answer]?
S1.- No.
Ad.- ***Why?***
S1.- Because it's not the definition of a rigid [material].
Ad.- Ok, but it is the definition for a kind of material…what kind of material is it for?
S1.- Elastic materials.
Ad.- Do you agree? Yes or no? Raise your hand before giving me an answer.
S2.- I think it's for plastic materials.
Ad.- So, what's the difference between plastic and an elastic material?
S2.- That plastic [materials], when you apply a force on them, do not recover their original shape. And elastic materials do.

EPISODE 4 (E#4; Y9.O9-Ad).

Ad.- [Consider you have] a football ball and a medicine ball of 3kg… have you ever played football with the second one?
S1.- No.
Ad.- No, ***why?***
S1.- Because it is very…
Ad.- Very heavy?
S1.- Yes.
Ad.- It's very heavy and very big. So, is it easy to hit the ball and score a goal?
S1.- No, it is difficult.
Ad.- Do you think that's because of the weight of because of the mass? Or because both of them?
S1.- Both of them.
Ad.- Ok, that's a question we are going to try to answer in a few minutes.

EPISODE 5 (E#5; Y9.O11-Ad).

Ad.- Let's think; ***what's the reason why when I throw the eraser, it stops?*** *It is because of the friction with the floor. Friction is a force applied opposite to the direction of the movement.*

EPISODE 6 (E#6; Y9.O19-Ad).

Ad.- "The acceleration that a force produces is inversely proportional to the mass of the body".

S1.- I think it's true.

Ad.- (…) ***Why do you think so? Tell me a reason why that's your answer.***

S1.- I think that is ok because the acceleration is proportional to the mass.

Ad.- Proportional? Right there it's said: 'inversely proportional', it's not the same.

S1.- Inversely proportional.

Ad.- Ok, what does 'inversely proportional' mean?

S1.-That when one number increases, the other one will not increase.

Ad.- It will decrease, so it's the opposite.

EPISODE 7 (E#7; Y9.O19-Ad).

Ad.- W*hat about (c)?*

S1.- I think it's true.

Ad.- You think it's true. ***Could you read it and give us an explanation why?***

S1.- With the same force, if we want to increase three times the acceleration, we should reduce the mass by a third.

Ad.- Ok, so?

S1.- I think it is like the example with the football and the medicine ball.

Ad.- Ok.

S1.- That if you…, if the force you are applying to the object, if the object is, is, eh…, lighter, the acceleration, eh…, will be more…

Ad.- Ok, we agree about that. I mean, we know that it's easier to move a light object than a heavy one. But now, we have to demonstrate that information using numbers, ok? And those numbers are talking about relationships that it's 3 times one by the other, or a third part one by the other, ok? So, we are going to imagine…, you are going to use number that are easy to deal with, that are easy to understand. Let's imagine a force of 30N. And we are talking about an object of 1kg. In order to make to make this mathematical equation real, which should be the acceleration?

S2.- 30.

Ad.- Yes? 30, ok, so. This is correct; applying a force of 30N to an object of 1kg, the acceleration should be 30m/s^2. It says that the force is going to be the same one, the same force. So, we are going to use again the same numbers. But later, it says that the mass should be reduced by a third. How much is a third of 30?

S3.- 10.

Ad.- Which one is going to be the number here in order to be a mathematical equation that is true?

S2.- 3.

Ad.- So, is it true that increasing three times the mass means decreasing three times the acceleration?

Ss.- Yes.

Ad.- So, that's true, ok? So, ***I don't want you only to tell me that it's true or not because of being lighter or being heavier, I want you to be able to look for an example an easy as this one.***

EPISODE 8 (E#8; Y9.O21-Ad).

Ad.- If I'm moving at a certain speed, whatever it is, but it's always the same, and someone comes from behind and pushes me, does my speed change?

Ss.- Yes.

Ad.- Because that is non-uniform. ***Why has my speed changed? What have they done to me when they pushed me?***

S1.- Apply a force.

Ad.- They have applied a force to me. And, since I have a mass, applying a force is the same as granting me one ...

S2.- Acceleration.

Ad.- Acceleration, indeed!

EPISODE 9 (E#9; Y9.O24-Ad).

Ad.- Do you know the meaning of the word 'proportional'? Or could you give two properties that are proportional? I mean, ***explain the concept using an example****.*

S1.- They are two properties, that if one goes up, the other [also].

Ad.- Ok, so, if one of them increases, the other one will also be increased. What if one of them get decreased?

S1.- It's inversely proportional.

Ad.- Well, but the other one…, I'm talking about proportional. The other one will also decrease. So, they have the same direction. (…). Could you give an example of that? Of two properties that increase together.

S1.- Eh…, the force and the acceleration.

Ad.- Ok, another one that is not the one here?

S1.- Eh… the mass and the acceleration?

Ad.- Well, let's try to forget about second law. Use another property. I mean, time, temperature, whatever, money, results, etc.

EPISODE 10 (E#9; Y9.O26-Ad).

Ad.- [T]here is fluid friction because it's difficult to separate particles from the fluid. (…) You can imagine that this particle of air is in this position [FN_EIA: pointing]. If we go right here with a car, we are going to change their positions. So, changing the relative position of the air is why there is a force of friction, ok? ***Because they don't want to change, and we are forcing them to change****. (…)* ***They are saying: 'I don't want to change'. So, I will apply a force in order to not to change. (…) That's a possible explanation for the force of friction.***

EPISODE 11. (E#11; Y9.O28-Ad)

Ad.- Is it the same than mass, or not?

Ss.- No.

Ad.- ***Could you give us an explanation why they are different?***

S2.- Because weight is a force, and mass is not a force.

Ad.- Ok, good. And will you give us the units of both of them?

S2.- Weight, kg.

Ad.- Really? Or weight, as it is a force, is measured in Newtons?

S2.- I don't know.

Ad.- So, mass, kg; and weight, as it's a force, Newtons. So, they have different units, which means they are different properties. They are not the same. But (…) they are connected, ok? An we are going to see that connection.

EPISODE 12. (E#12; Y9.O28-Ad)

Ad.- The moon has a lower gravity just because it is much smaller than our planet. And the acceleration of gravity is related to the mass of the body that we are considering.

EPISODE 13. (E#13; Y9.O28-Ad)

Ad.- The weight is going to change. ***Why?*** *What is changing in order to say that the weight changes? [silence]. (…) What is the only property that you can change? The gravity of the planet. Is that clear?*

EPISODE 14. (E#14; Y9.O29-Ad)

Ad.- Are the same weight and gravity?

S1.- No.

Ad.- No? ***what's the difference between them? Could you give me an explanation for the gravity? Or what do you think the gravity is?*** *Is it a force?*

S1.- Yes.

Ad.- And how does it work? [silence] Does it repel us from the surface of the planet? Or does it attract us?

S1.- Attract us.

Ad.- Ok. So, that's the gravity. We can say that the gravity is the force exerted by a planet, by a satellite, by a star, whatever, and it attracts the mass. So that's the gravity. What's the weight?

S2.- Something that you can…, eh…

Ad.- So, for example, how often do you say 'my weight is 50kg'. Are you talking about your mass if you say that?

Ss.- Yes.

Ad.- So, we are studying forces, and we are talking about mass… are they the same? Or did we say that they are different because they have different units? [silence] We said that they are different, so, they cannot be the same. So, if we use in a sentence 'my weight is 50kg', we're making a mistake. Remember we were talking about the difference of using everyday vocabulary; it is ok, but if we are using the scientific one, weight is not mass. Weight is the force that is applied by a planet in order to attract us. So, it is the same as talking

about the gravity. Ok? So, for us, from now on, weight means the same than gravity

EPISODE 15. (E#15; Y9.O29-Ad)

Ad.- What about 'B'?

S1.- 'Does it have the same weight?' No, because in the moon, the weight is lower.

Ad.- And why is it lower? What is also changing?

S1.- Eh…, in the Earth surface, it's 9.8…

Ad.- So, in order to calculate the weight, we are considering both mass and acceleration of gravity, ok? So, is the mass changing?

S1.- No.

Ad.- No, you told me that it is the same, all right. ***Is the weight changing?***

S1.- Yes.

Ad.- Why is it changing? Because the acceleration is changing. *Could you tell me both values?*

S1.- In the Earth surface, 9.8.

Ad.- All right.

S1.- And in the moon, 1.6.

Ba- Ok.

EPISODE 16. (E#16; Y9.O30-Ad)

Ad.- ***Why does the pen stop and why does it start to come down?*** *What is happening there for this phenomenon to occur?*

S1.- Weight.

Ad.- Weight, which is the same as ...

S2.- And also gravity.

Ad.- And also the gravity. Well, are they the same, or are they two different things? Are they two forces that are acting simultaneously, or are they really the same and are we using two different ways to call them?

S2.- They are different.

Ad.- They are different ... Well, let's see if that's the case or not.

EPISODE 17. (E#17; Y9.O30-Ad)

Ad.- ***You know that the gravity on the Moon is not the same than on the Earth…***

S1.- Because the is no oxygen.

Ad.- Well, it's not related to that. We'll see it. It's the other way around: there are less oxygen because there is less gravity, ok? But, anyway, we don't need to consider the composition of the atmosphere.

EPISODE 18. (E#18; Y9.O31-Ad)

S1.- I have a question about gravity. If you have…, if you throw to the air, for example, a Helium balloon, it does not go down…

S2.- Because there is another force.

Ad.- Yes, there should be another force. Because if we throw whatever it is, if you are thinking about gravity, because of it, it should go down.

S1.-No!

Ad.- Yes! If there is only gravity, it will go down. But we know it [the balloon] goes up. So, that's because there is another force that is stronger; it means, more Newtons. So, as this is stronger, the resultant one, the total force, is in that direction [FN_EIA: pointing up]. *So that's why it goes up. But we still don't know how we call that force. But it exists, ok? (…)*

S1.- But the Helium balloon never goes down!

Ad.- Well, it would eventually… because it could lose some air…, I mean, it could lose some Helium, and it would go back, ok? But if it's perfectly closed, it will leave the atmosphere.

EPISODE 19. (E#19; Y9.O31-Ad)

Ad.- Is it easier to move a wardrobe or a table right here, in this floor, or in the beach?

A1.- Here.

Ad.- ***Here is easier, why?***

S2.- Because in the beach the surface is not smooth.

Ad.- It's not smooth, there are more irregularities, it is the same. So, the properties, the quality of the surface always is going to influence the value of the friction, ok? So, the more irregularities there are, the harder is going to move something.

EPISODE 20. (E#20; Y9.O31-Ad)

Ad.- Have you ever heard about a magnetic train?

Ss.- Yes.

*Ad.- **Why is it so fast?***

S1.- Because it has only one friction, that is the air.

Ad.- Ok, and what is the one that is not happening?

S1.- The floor.

Ad.- The one with the floor, ok? So, if you want to go faster, it is better not to have friction. If we want to be safer, it is better to have friction.

EPISODE 21. (E#21; Y9.O32-Ad)

*Ad.- **Why did you said, when we were talking about throwing a ball, that it will stop sooner if you throw it in the beach, I mean, in the sand, than if you throw it in a skate park?** What's the different between both places?*

S1.- That in a skate park, the…

Ad.- The surface…

S1.- The surface is smooth, and in the beach, the surface is like the other way.

Ad.- Yes, so, when we are talking about the force of friction, is it higher in the skate park, or in the beach?

S1.- In the beach.

*Ad.- **And that's because…***

S1.- Because it has more…

Ad.- The key word is 'irregularities', ok? so, we can say that if there are more irregularities, it is easier to be stopped; it is, it will be stopped sooner. if there are no irregularities, it will be stopped later, ok?

EPISODE 22. (E#22; Y9.O33-Ad)

Ad.- Have you heard about the magnetic levitation train? It is basically a train, making it much simpler than it really is, in which there is a magnet below and another magnet above. What about the magnets with each other?

Ss. They repel each other.

*Ad. They repel. Well, to a certain extent, this train, when travelling, does so without touching the rail. **Why is it much faster?** Because there is no friction force. Because there is no contact with the surface. There is no frictional force on the rail; there's on the air (…)*

S1.- But does it fail?

Ad.- If it fails, it does not move. As if a common train breaks.

S1.- Ok, but if, for example, one of the two magnets fail…? The train derails and you get yourself killed!

Ad.- No, Gosh, don't be so dramatic. The only thing that happens is that the magnets are no longer separated, and then, the train rest on the rail. It will be supported on the rail. And if it is stopped, it does not run. That's all the happens.

S1.- But don't you die.

Ad.- No, you don't die.

EPISODE 23. (E#23; Y9.O33-Ad)

*Ad.- **What makes ice more desirable as a surface for this sport?***

S1.- Because it is more slippery.

Ad.- It is more slippery, which is the same as saying that ...

S2.- It is more slithery.

Ad.- It is more slithery, which is the same as saying that ...

S3.- That it has less irregularities.

Ad.- That it has less irregularities, which is the same as saying that ...

S3.- That there is less friction.

Ad.- That there is less friction, that there is less...

S4.- Friction force.

EPISODE 24. (E#24; Y11.O1-Ad)

Ad.- The slides tells us that all bodies fall with the same acceleration, independently of their mass. That is, a feather must fall at the same speed as a stone. Is that true in real life, or not?

Ss.-No.

Ad.- And what do you think it changes, being this a Galileo's statement?

S1.- The weight.

Ad.- Isn't the weight the same as the mass, in the end?

S2.- Yes.

[Silence]

Ad.- Aren't they always the same?

S3.- Yes.

Ad.- If the mass does not influence, by multiplying it by g, the weight does not have to be the determining factor.

S2.- Can you repeat the question?

*Ad.- Yes. If all bodies fall with the same acceleration, which is independent of their mass, **why do we think that a stone and a feather do not fall with the same speed?***

S4.- Because one takes less.

Ad.- That's the same thing I'm asking.

S5.- The time.

Ad.- It's not the time ...

S6.- The resistance.

Ad.- Let's see, tell us.

S6.- That the feather offers resistance.

Ad.- Let's see, let's do a test, with the feather being a sheet, and the stone being a paper ball. Look. Would you say that these two folios have approximately the same weigh?

Ss.- Yes (...).

Ad.- With these two folios that have the same mass, I make a ball with one, and I leave the other as it is. If you observe the fall, it does not imply the same final velocity. So, the ball falls well before. And do you think the mass is the same?

Ss.- Yes.

Ad.- Then, if the mass is the same and they fall at different speeds, is the mass an influencing factor?

Ss.- No.

Ad.- No. In this case, what determines the difference between one case and another is, as you said, the force of friction, right? In the cases we are analysing, it is assumed that the bodies do not have friction. If there were no friction, as the mass is the same, the acceleration of gravity would also be, and, consequently, the two would fall at exactly the same speed. What happens is that this is an ideal theoretical framework. And we know that practical reality is slightly different. But that does not mean that this is not true. What it means is that we are changing the conditions. In any case, we are saying that the mass is a factor that is not at all influential in terms of the speed of free fall, okay? All right.

EPISODE 25. (E#25; Y11.O1-Ad)

Ad.- Tomorrow we will mark the exercise together, okay? I do not want you to be able to copy it from the photocopies, but to be able to ***explain it. To be able to, to some extent, tell the others how to solve it correctly.***

EPISODE 26. (E#26; Y11.O7-Ad)

Ad.- Note that the dimensions of the angular velocity are t^{-1}. ***Why does only time appear in angular velocity?*** *What did we say about angular magnitudes not having dimensions? What did we comment yesterday about it that surprised you a little bit?*

S1.- That they have no dimensions.

Ad.- We said that they did not have dimension. ***Why don't they have dimensions?***

S2.- Because they were dimensionless.

Ad.- Okay, that's the same, but with another word. ***But why is it dimensionless, or why does it have no dimensions?***

S3.- Because the dimensions have to disappear when we do a calculation.

EPISODE 27. (E#27; Y9.O7-Ad)

Ad.- ***Could you explain what's happening here?*** *What are we talking about? We are talking about springs. There is a mass hanging from that spring. The thing is that this first mass is a fourth part of this one, or, what is the same, this can be considered four times the first one, ok? So, this one is heavier, of course. And because of being heavier, that's why this spring is longer, ok? So, there should be a relationship between the mass that is hanging and the length of the spring, ok? So, if we've put more mass, the spring should be longer.*

EPISODE 28. (E#28; Y9.O12-Ad)

Ad.- Did you all finish [the reading]? Ok. Could somebody explain me the Hooke's Law? What about you, Agnes? What did you understand while reading this? What are we talking about? What are we seeing?

S1.- A force.

Ad.- Ok, but the thing, I mean, the change that we are measuring is… there are some springs, and those springs are longer or shorter, just because of the…?

S1.- The extension.

Ad.- Ok, just because of the extension… but is it because of the mass, or not?

S1.- If you have more mass, the spring is going to be longer.

Ad.- Ok, you are saying that we have a relationship between the quantity of mass and the length of the spring. (…) Is there a mathematical equation to explain that pattern?

S1.- Yes.

Ad.- And that Law is called…?

[Silence]

Ad.- It's written here; it is called Hooke's Law.

A.6. EXPLANATION-BUILDING EPISODES IN BECCA'S OBSERVED LESSONS.

EPISODE 1. (E#1; Y9.O1-Be)

*Be.- In the protocol, it was said that the thermometer could not touch the bottom of the glass or the walls; **why do you think it was said that?** Because if you put the thermometer touching the bottom of the glass, which is in direct contact with the plate, what are you measuring what will be: the temperature of the water or the temperature of the plate?*

S1.- Of the plate.

Be.- Of the plate, but that is not what we wanted to measure.

EPISODE 2. (E#2; Y9.O2-Be).

*Be.- **Why was it necessary to chop the ice?***

S1.- Because if we put big pieces, the experiment takes more time.

S2.- Because if we use pieces too large, they do not fill gaps that are missing, and then, the thermometer does not get in touch with everything.

S3.- Because it takes longer to become liquid.

S4.- Because it would not mix well with salt.

S5.- Because if you crush it, it's all together and there are no air gaps.

Be.- And what consequences can this have?

S4.- That the thermometer would take the temperature of the air.

Be.- We crush to have a homogeneous substance, so that what we measure is more real.

EPISODE 3. (E#3; Y9.O2-Be).

Be.- We are going to use a cooperative-work dynamic that we all know very well: the 1-2-4 (for us, the 1-2-table). You will have a minute to think individually, a minute to share as a couple, and a minute to reach agreement as a whole team. I'm going to write an observation on the blackboard, and we'll get a question from it. Then, first in an individual way, then in pairs, and then as a team, you have to think a hypothesis ... what was a hypothesis?

S1.- A hypothesis is what you believe before having the result.

Be.- And?

S2.- It is an idea that you have of something.

S3.- It may be true or not.

S4.- You do not know what can happen.

S3.- You have to check it.

*Be.- It is an idea that must be provable. We are not going to ask ourselves if an experiment can be done to prove it. There are ways, but we are not going to question about them. You imagine that there is some experiment that can be done to demonstrate the hypothesis that you think. Ok, **the observation is: "the temperature remains constant during a change of state".** Have we observed that in the laboratory?*

SS.- Yes.

Be.- ***The question is 'why?'.*** *You have some minutes to think, go! (…)*

S1.- Because when changing from one state to another, it remains at an average temperature between the two states.

S2.- We think that it is due to the atmospheric pressure.

S3.- When changing from one state to other, the particles are separating little by little during a certain time. And at that moment the temperature is constant. In the solid, the particles are joined. And in the liquid, they are separated. At the end of that process, the change in state has taken place, and the temperature continues to rise.

S4.- We think that the temperature remains constant because it takes some time to reach a certain temperature..., mmm, because it warms up very slowly.

S5.- We think that you the change must be identified, and because of that, the raising or lowering of the temperature stops… we must identify when it changes state to know when it has changed to liquid ... there is a moment when it has finished changing its status ...

S6.- Because it takes time to change the temperature. There are certain temperatures that are more difficult for the liquid.

S7.- The temperature remains constant because as it is neither one state nor the other and it is a process, it needs to have a temperature that does not vary, so that it can pass to the next state. And when the state changes, the temperature begins to rise.

Be.- Ok, now we are going to try to look for information about this, to see if someone can help us clarify this. With the help of your i-Pads, look for a hypothesis; it's a teamwork. We can pose the question in a different way: that energy that I am releasing to the matter in the form of heat…, what is happening to it? where does it go?

S1.- The heat energy is focused on changing the state of the water and not on raising the temperature. That is, the energy is focused on the change of state.

S2.- The energy focuses on separating the molecules.

Be.- Let's see. How are the particles in a solid? They are together and organised. And when I give them some calorific energy... how are the particles of the solid: quiet or moving?

SS.- Moving.

Be.- And what was the name of that movement of solid particles?

SS.- Vibration.

Be.- So, by providing them with some calorific energy, will the particles start to move faster or slower?

SS.- Faster.

Be.- That is, the energy makes the particles move faster. Well, there comes a time when the calorific energy is spent in those particles that moved only in vibration… Do you remember when we went out to the playground and we did the activity of 'I am a solid', that we did not move? Well, for that energy, my group's companions have bothered me so much that in the end what I want is to move, and I become a liquid. Liquids flow. If we continue to increase the temperature, the particles will move even faster, until there comes a time when that energy is spent in transforming the liquid into gas. And the gas particles, how did they move?

SS.- In 3-D.

Be.- In 3-D, very well, and occupying all the possible space. That is, the temperature remains constant because the energy we give to it is not spent in raising the temperature, but in changing the order of the particles, so they move from one state to another state.

EPISODE 4. (E#4; Y9.O5-Be)

S1.- "Miss, you could squeeze a bowl [full of liquid] ... If the particles started to come closer and closer, in the end, it would become a solid, right?"

Be. - No!! ***Why?***

EPISODE 5. (E#5; Y9.O6-Be)

Be.- We said that water is made up of oxygen and hydrogen...so, ***why is it not a mixture that is made up of two things?***

S1.- Because it is formed by two elements.

Be.- And what else? What other condition must it have so that we can say that it is not a mixture but a compound?

S2.- Because you cannot ..., ehm, decompose.

Be.- But I'm going to break it down! With a chemical reaction. Look, what I should see very clearly (but it seems to me that if it is not working already is because the battery is worn-out; tomorrow we'll bring another battery) is that more bubbles are formed in a pencil than in the other ... ***why? Why could it be?***

S3.- Because one has more graphite.

Be.- No, I do not care about the pencil that I use.

S4.- Because water has more component ..., more ...

Be.- More what of what? What was the water like?

SS.- H_2O.

Be.- Ok, then, each molecule of water… what is it made of?

S4.- Two elements.

Be.- Okay, but it will have two [atoms of] hydrogen and one [atom of] oxygen. I mean, it has double ...

S5.- ***Why?***

Be.- Because the water molecule is like that. Come on, we're getting off the topic (...) Let's see, the experiment we're doing is to prove that water is a compound and it's not a mixture. It is formed by two elements, which are hydrogen and oxygen. And we will check, tomorrow when I bring a new battery, if it works, that in one of the pencils more bubbles are formed than in the other, twice as many bubbles are formed in the other, because water has twice the hydrogen that of oxygen, okay? We will not be able to measure exactly how much oxygen comes out or how much hydrogen, but in a laboratory with the right materials you can collect the amount of hydrogen that comes out and the amount of oxygen. And you can verify that it should be double.

EPISODES 6-7-8-9. (E#6, E#7, E#8, E#9; Y10.O2-Be)

[FN_EIA: In their videos they include explanations to the experiments, based on the laws they know].

S1.-If we put the bottle in hot water, we will see that the walls of the balloon expand, because the heat causes the particles of the gas to move faster and go further: that is why the balloon expands. But if we put it in icy water, we will see how the balloon decreases, since the cold makes the particles of the gas do not move so fast or go so far.

S2.- As the volume increases, the particles take longer to reach the walls. That is why they collide less times per unit of time against them. This means that the pressure is lower, since it represents the frequency of gas [particles] collisions against the walls. When the volume of the container is smaller, the gas particles take less time to reach the walls and collide, and therefore, more collisions do occur, and the pressure increases.

S3.- This happens because when the pressure of the gas decreases, the volume of what is put in here increases, as the Boyle-Mariotte law says, that they are inversely proportional.

S4.- This happens because when the pressure of a gas in a container is increased, the gas particles take longer to reach the walls. And this means that they collide less against each *other, so the pressure decreases, since the pressure represents the number of collisions of the particles.*

EPISODE 10. (E#10; Y10.O3-Be)

Be.- Now, I have a container filled with a gas, with a moving piston, like the syringe that many of you have used in your experiments. Now, if I raise the temperature - I do not care which law is, now we think about it. I am just making a reasoning -, what will happen to the particles of that gas: will they move faster, or will they move slower? Faster, right? If they move faster, they will push the piston so that the volume will…, they will try to occupy greater volume. If I increase the temperature, the volume will increase, as long as I keep the pressure constant.

EPISODE 11. (E#11; Y10.O3-Be)

Be.- Now, instead of keeping the pressure fixed, we will keep the volume fixed, we will keep it constant. How? Well, instead of putting a container with a piston, we have a closed and rigid bottle. I have a gas there, and I increase its…, I heat it up, I increase the temperature. What will happen to the pressure: will it increase or decrease?

SS.- Increase.

*Be.- **Why?***

S1.- Because they are directly proportional, temperature and pressure.

*Be.- **Yes, but I want you to explain it to me according to what happens to the particles**. What happens to the particles when they are heated up? The particles of a gas that are separated and disordered, I heat them up, in the fire, with a dryer, … What happens to them?*

S2.- They separate and move faster.

Be.- They will move even faster, and they will separate more. So, what will happen? will they hit the walls of the container more times, or less?

SS.- More.

Be.- That is, if the temperature increases, the pressure increases. Good!

EPISODE 12. (E#12; Y11.O1-Be)

*Be.- Do you remember that we saw the [concept of] solubility? What was solubility? The maximum amount of solute that I can dissolve in a certain solvent at a certain temperature. It will be related to the [concept of] saturated solution. What did it depend on? It depended on the amount of solvent that I have, on what solvent I have and on what solute I want to dissolve, and on what else? On the temperature. Because if I warm up ... Imagine that this is already the saturated solution. If I heat the water up, [the solute] will dissolve. And that is called 'supersaturated solution', because we have managed to put more salt, more amount of solute, than what really fits there. And now I ask you, **why do you think it fits more, or that I can dissolve more, when I have heated it up?***

S1.- Because the atoms move more.

Be.- Indeed, because the atoms move more. And if we have the supersaturated [solution] and it is cooled down, what will happen?

S2.- It separates.

Be.- All that did not fit at that temperature precipitates again to the bottom. That is why the solubility had to be defined with respect to a certain temperature.

EPISODE 13. (E#13; Y11.O1-Be)

Be.- What did we wanted to do this experiment for? Do you remember?

S1.- To see something related to the density…

Be.- For something about density, ok. So, we were saying that this is pure water (well, let's suppose it's distillate water, although it's tap water), and the egg is our density meter. We put the egg, and it sinks (…). Now, we add some salt.

Be.- What happened before? That the egg had sunk. ***Why?*** *How was the density of the egg compared to the density of the water before?*

SS.- Higher.

Be.- Higher, and that's why it was sinking. We'll study that when we get to the topic of hydrostatics (…). Well, we have added salt, we have managed to change the density of the water, and now… is the water denser than the egg, or the egg is denser than the water?

SS.- The water is denser.

Be.- The water is denser, so…

S1.- But the egg weighs more!

Be.- But here we are not talking about weight, but about density. We'll do this again when we are in the topic of hydrostatics.

S2.- Is the sea water saturated?

Be.- Well..., I do not think so, but it's a good question, why do not you research about it?

EPISODE 14. (E#14; Y11.O3-Be)

Be.- Solubility depends on the temperature. ***It's true. Why?*** *Because we had said that, at higher temperatures, the particles of the solvent moved faster and there was more space for the particles of the solute to fit.*

EPISODE 15. (E#15; Y11.O3-Be)

Be.- Now, question: ***why does the book and the paper fall at different speeds when they are separated, but fall at the same speed when they are together?***

S1.- Because they behave like a single body.

Be.- ***Why?*** *Ok, I change the question.* ***Why does it take longer for the paper to fall than the book when they are separated?***

S2.- Because the book weighs more.

Be.- Sure? Now let's make a ball with the paper. We drop them at the same time: 1, 2 and 3! Now, what?

S3.- They fall at the same time.

Be.- But you said that the paper took longer to reach the floor because it was less heavy than the book… when making a ball with the paper, has its weight changed? SS.- No.

Be.- But now they have fallen at the same time… curious… ok, sit down.

EPISODE 16. (E#16; Y11.O3-Be)

Be.- Let's see. If I threw this [FN: book plus paper], was it there one that fell faster, or did both fall the same way?

S1.- The book falls faster because it is heavier.

Be.- Because it is heavier… but if we made a ball, and we threw it, they fell the same ... and this [the paper] weighs less than this [the book] ...

S2.- But more air passes…

Be.- Trough where?

S3.- Because it is not a flat surface, there's no air that slows it down…

S4.- Molecules are closer together in the crumpled paper.

Be.- So, if I drop the book or the paper... We have to calculate how fast this paper falls. I give you another opportunity. I am asking you to calculate the speed, not the time it takes to fall... How do you calculate the speed?

S5.- There is a formula.

S4.- It is accelerated.

Be.- If I drop the paper, will it fall with a constant speed or will it go faster and faster? Or will it go increasingly slow?

S6.- Increasingly faster.

S4.- Constant.

Be.- We have three possibilities: that it always goes at the same speed, that each time it goes faster or that it decreases its speed. What do you think it's going to do? But do not look for it in the book, try to think about it by yourselves.

S6.- It will increase, because at first it is motionless, and then, the longer it goes, the faster it will go.

Be.- ***You say that speed is constant, why?***

S4.- Because there's nothing to push it down.

S6.- Yes there is: the gravity!

Be.- look. Imagine that I jump from this table. Imagine that, instead of jumping from the table, I jump from the balcony of my mother's house, which lives on a fourth floor. Do you think that the effect on my body will be the same if I jump from the table or from my mother's house? My mass is the same in both cases...

S7.- Due to the acceleration of gravity.

Be.- And what is that?

S7.- The 'g'.

Be.- Let's see. ***Why is it more dangerous to jump from the balcony of a fourth floor than jumping from the table?***

S8.- Because there is more distance to travel.

A.- And having traveled more, it will fall with more force ...

S7.- Due to gravity.

Be.- Ok. I already think that more or less everyone is in this. The objects do not fall with constant speed, they fall accelerating. Yesterday we said that today we were going to study the free fall movement, which is a type of UARM.

A.7. EXPLANATION-BUILDING EPISODES IN CHRISTIAN'S LESSONS.

EPISODE 1 (E#1; Y8.O1-Ch).

S1.- ***Why not 'YY'?***

Ch.– You cannot have such a thing, because all eggs are X's, right? Sperms are 50% Y's and 50% X's.

EPISODE 2 (E#1; Y10.O1-Ch).

Ch.– So, I have a question for you this morning. To discuss in pairs. So, you two, you two… 30 seconds, first of all. How does heat travel in solids? [FN_EIA: "dice of Destiny"].

S1.– Mmm… conduction.

Ch.– Conduction. Excellent, very good, well done. Can anyone describe how is the conduction process happening? Anyone be brave and have a go! Claude.

S2.– Mmm, vibration gives heat, ahm…, gives more energy to the particles, so they vibrate more, and the vibration causes […].

Ch.– ***Very good effort at explaining****. Very good, yeah. Anybody has something to add?*

S1.– So, the energy is transferred along…

Ch.– Yeah. So, it has to do with the vibration and the kinetic energy of the particles in the solid. Anybody wants to go a bit deeper?

S1.– Oh! Is that free electrons that…?

Ch.– Excellent. So, free electrons, what kind of materials may have electrons that are not tightly held?

S1.– Metals.

Ch.– Excellent, ok? And they are… aim to do what, these free electrons? (…) Just a little demonstration of this. Ahm… if I was holding a metal stick, yeah?, and one end of the metal stick is put into a very hot flame here, well, what would happen to my hand?

S2.– It will get burnt.

Ch.– I will get burn, all right? Ok, so, what about this? This piece of wood, ok? If I hold it in there, what's gonna happen to my hand?

S2.– Nothing.

Ch.– Nothing at all. ***Why not?***

S3.– The conduction… it's an insulator.

Ch.– What's an insulator? The wood is an insulator. (…). I have been holding this for at least two minutes. There you go. If that was a metal, how long would it take to my hands to be burnt?

S4.– Few second.

Ch.– Few second, yes. How long does it take, when you are heating one end of the metal bar, for the heat to reach the other end?

S4.– Few seconds.

Ch.– Few seconds, yes. How long have I been heating this for?

S2.- A couple of minutes?

Ch.– Yes. So, what is it that glass and wood don't have in their structure that metals have?

S1.– Free electrons.

Ch.– Free electrons, ok? So, all the electrons are used in… bonding, yes? They are not able to sort of, move freely, ok? At a certain point the flame will reach my fingers, yes? Clearly it is very hot on one end, but it's not hot, this end. I mean, trust me. You hold that in… you did in a bonfire? You can toast a marshmallow… this end, could be, you know, 500 degrees, in the flame. But this end, not. So, the heat is not travelling, or at least, it is not travelling very well, ok? All right.

<u>EPISODE 3 (E#3; Y10.O1-Ch).</u>

Ch.- Second question for you this morning for you to work in pairs: how does heat travel in fluids? 30 seconds. 'How does heat travel in solids', we talked about that. Now, how does heat travel in fluids? Your 30 seconds start now. (…). Celia, how does heat travel in fluids?

S1.– Mmm…

Ch.– In solids, heat travels by conduction. But, how about in fluids? So, in liquids and in gases. How does the heat travel?

S1.– [Silence].

Ch.– Pass it on? Do you know? No? Ok, anyone else? Camille?

S2.– Convection currents.

Ch.– Convection! Not conduction, but convection. So, it conveyed by these currents. Ok, ***can anybody explain a bit more this process?***

S3.– [inaudible].

Ch.– The only thing you are not sure about is whether the area of the fluid becomes more dense or less dense when heated. What do you know about the particles in the area that is being heated?

S1.– They move faster.

Ch.– They are moving faster, so they are going to take more space. If the same amount of stuff takes more space, is it less dense, or is it more dense?

S1.– I don't know.

Ch.– Ok, what's the formula for density?

[silence]

Ch.– Density equals mass divided by volume, ok. If the same amount of mass takes up a bigger volume, is this number bigger? No. So, the density of hottest stuff, of hottest fluids, is…

S4.– Less.

Ch.– It's less. Ok, all right. Yeah? So, you've got the angels here, and, at the moment, they are completely still, yes?, not a lot of movement. But if we put a heat source under them, the air is being heated above the flame, which means that their particles are moving faster, which means they need to take more space, which means that area of air is less dense. So, less areas move up, yeah? (…) Ok. Well, we've got a short video to watch, and you are going to make predictions in the middle of this video. And then, they'll show us an experiment, and you can see if you were wrong or right. Ok, it's a video about conduction, well, not really specifically conduction, it's more to do with insulation.

EPISODE 4 (E#4; Y10.O1.P-Ch).

Ch.- Now, draw a quick picture here, so now we've got a piece of material like that, and another piece of material, like that, ok? So, I put an ice cube on the top of it, there's our ice cube. Ok, now, this one feels cold. The surface feels cold, yeah? And what he said about this one? Just it doesn't feel cold. Surface feels cold here, surface doesn't feel cold. So, this one, definitely feels cold, this one doesn't. They are the same temperature, but this one definitely feels cold and this one doesn't feel cold. I think he said this one was heavier and this one was lighter? Ok. Heavier material, and this one is lighter material. They look quite similar, both are dark. Draw an ice cube on top… ice cubes melting. (…). They are no longer on the freezer. Now, let's make a prediction. Same shapes, same length, same depth… the ice cubes you are using are the same size, as well. We need to make a prediction, guys. So, they are going to melt, right? The kitchen is not below zero, right? It's comfortable, it's 20 degrees. So, the ice cubes are gonna melt. So, either they are gonna melt faster one or the other, or they are gonna melt at the same rate. And if they melt faster one or the other, which one is gonna melt faster? This one feels cold, this one doesn't feel cold. It's the only difference, really. Ok, well, this one was heavier, this one over here is lighter. So, what do you reckon, guys?

S1.– Would it be that the one that doesn't feel cold…

Ch. – It does what?

S1.– The ice melts quicker in that one.

Ch.– Ok, so you think that the one that is on the surface that doesn't feel cold melts quicker. What about you, Carla? You say that this one melts quicker… Claude?

S2.– The right one.

Ch.– This one will melt quicker? [FN_EIA: pointing to one of the drawings]

S2.– Yes.

Ch.– Ok. Chase? Same melting? Or if they have different rates, which one melts quicker? This one? The one that doesn't feel cold will melt quicker? Ok. So, at this moment, we've got 1,2,3 people… well, no, 6 people who say that the one that doesn't feel cold is gonna melt quicker. One person says that the one that feels cold will melt quicker. Now, Chase, ***why do you think that this one is gonna melt quicker?***

S3.- Because it doesn't feel cold, and it should in a way says it's warmer, it's because [inaudible] some heat on it. And… that's all, I don't know.

Ch.– Ok. Thank you very much. And, Claude, what about you? You said that the one that feels colder will melt quicker.

S4.– Because that's a better conductor heat.

Ch.– Ok, ok. And what makes you think that is a better conductor heat?

S4.– Ahm…, it feels colder and heavier, so, it seems like it is a metal.

Ch.– So, metals, in your experience, feel colder, yes? So, this is at the same temperature than this, ok? Feel the metal, hold it, feel the plastic. (…). This feels cold, yes? So, Claude says that, in his experience, the metals feel colder, and they are better conductors, so he thinks this one melts better. Ok, fair enough. So, different perspectives. This one feels warmer, so, there is more heat in it, so the heat will get into the ice cube. Yes? Ok!

(…) [The video goes on]

Ch.– ***Can you try to explain that?*** *So, if we write down what happened, yes?... Ok, so, the ice cube on the surface that feels cold melted much quicker, that's what happened. That's the observation, yeah? 'The ice cube on the surface that feels colder melts quicker'. Ok? Why? What are the key words here? What are the key words that we need to put into our explanation?*

S4.– Energy.

Ch. – Thermal energy, that's good. What else?

S1– Insulator.

Ch.– Insulator.

S2.– Conductor.

Ch.– Ok.

S3.- I'm not sure how to write the explanation.

Ch.– We're gonna write it, but before we do, we're gonna put down some key words that we need to put in there. Now, when you are sitting on a metal fence on a cold day, you feel it cold. If you sit or rest on a wooden fence, at the same temperature, it doesn't feel cold. So, your body is at about 37 degrees, the outside is about 5 degrees cold, and the heat from your body goes to the inside of the metal so quickly. It's not going into the wood, because the wood is an insulator, ok? So, materials that are conductors, will take the temperature difference, so they will move the heat energy across from the area […]. All right? So, what are the key words here? Thermal energy, insulator, conductor…

S3.- Metal.

Ch. – Yeah, we've got metals! If we put 'metals', we could put 'plastic', 'wood', yeah, things that are insulators. Anything else you think it's key for this explanation? Because, you're gonna have two minutes to write an explanation about this phenomenon. Do you think we need anything else?

S4– Transfer?

Ch.– Transfer, ok… it's about how energy is transferred, so you'll need to be using the word 'transferred'. That's good, yeah! That's all? Fair enough! Then, two minutes to put in paper why this one melts quicker. If you want to explain it really well, then include those words. Your two minutes start now. (…).

What you're gonna do, you're gonna read out your explanation so far to the person sitting next to you, ok? So, you've got to take turns for listen, and then, read yours. (…).

Now, having listened to someone else's, is there any way you think you could improve yours? Something you could add to yours? You've got one minute to add something that, after listened someone else's explanation, you say 'Oh, I like that!', or 'I wanna use that word'. You've got one minute to improve your explanations. (…).

EPISODE 5 (E#5; Y10.O1.P-Ch).

Ch.- Guys, there is an ice cube, ok?... 1,2,3,4,5,6,7… so, normally, we do 4 pairs, but today it's 3 pairs and one person works on their own. So, we've got an ice cube and marble, which is really dense (…). You've got to heat… the water is gonna be for… all you have to do is this, ok? So, you pour some water in, all right?

S1.– To heat the marble.

Ch.– Well, the marble is at the bottom, right? So, what you're gonna do, after pouring the water, you're gonna tilt it, and heat it near the top, ok? Heat it near the top and see what happens. (…). Obviously, we could get the ice cube to melt, if we heat it. You're heating here, and it took, what?, three minutes, four minutes? Quite a long time, isn't it? It took 3-4 minutes for the heat to get from there down to there. And it's really hot there, ok, that's fine, amazing! (…). Let it cool down. it finally smelt, but it is very slow… it needs to travel through the water. Well, the thing is that if you've got water on top of all of that, ok?, there is water, a continuous line of water, between the ice cube and the top. Can you see that? It's very difficult to get… so it's not necessarily the marble, but there is water in contact with the ice cube, but it doesn't melt, yeah? Ok. So, another diagram, guys. Ok, here we go. So, (…), you've got an ice cube, and then, you've got the marble. And you've got water and you're heating here. Now, Cecile, what happens to the water when you're heating it?

S2.– It's boiling.

Ch– It's boiling, right? So, what temperature is that, Cecile?

S2.– 100 ºC.

Ch.– Yes, so, these bubbles of water vapour are being produced, yeah? So, the water, the particles are moving so fast that they are scaping the surface of the water to go into the air. Ok? Boiling. But what happen to the ice cube, Carl?

S3.– It stays solid.

Ch.– Ok, yeah. So, here we go: heat…ok, so, the explanation: even though… well, not the explanation, the description: 'even though the water at the top was boiling, the ice cube stays solid'.

S2.– Well, it eventually melted.

Ch.– Yes, it eventually melted. Claude was heating probably too long, the first group, they were heating for, at least, three minutes, maybe more, maybe five minutes, and after five minutes, eventually the ice cube melted. So, the heat did travel down the water, but only very slowly, ok? ***Now, why is that?*** *So: solids for about five minutes (maybe exaggerating a little bit) ...* ***Why? Why is this?*** *Does anybody get any suggestion?*

S2.– Oh! Is it like to do with the fact that conduction doesn't work very well in liquids?

Ch.– Perfect answer, yeah? That's what the book would tell you. That's what physics would tell you. Liquids are not good conductors of heat, ok? Water is not a good conductor of heat. If you have mercury, which is a liquid metal, we assume that the liquid is gonna conduct better than water.

S3.– And what about gases?

Ch.– Gases are even worse at conducting. Which is why in your houses you might have two brick walls, one brick wall in the outside and one brick wall in the outside. And there *is an air gap, and hat air is insulating your house, because it doesn't allow conduction. You might have some […] in there, which has even more insulating effect, but you might have just a gap air, because air is a really bad conductor.*

S1.– Should we write the why?

Ch.– Ok, Chris has told us why, I hope you all listened. But, please, Chris, tell us one more time.

S1.– Yes. Conduction doesn't work very well in liquids.

*Ch.– Perfect. **That's the explanation**. I can put it in there. I'll put it doesn't work well in water or liquids generally. Camille, what would you say about air conducting? And generally, in gases, compared to liquids?*

S5.– Eh…, they are not good conductor.

Ch.– So, which is better conductor: liquids or gases?

S5.– Eh…liquids.

*Ch.– Liquids, yeah! So, solids, that's where conduction happens, you know, faster. Liquids are not really good at conducting, and gases are even worse. Yeah? And **why is that? Why is it that gases are even worse at conducting heat?** What is it about the structure of a gas, of the particles in gases?*

S3.– They spread very far.

Ch.– Excellent. Gases are even worse at conducting heat. So, it's all about transferring these vibrations from one particle to the next, and in gases, they spread so far apart that it's even slower than in liquids. In gases, conduction still happens, but very slow. If you have double glassing at home, rather than air between the two panels, it would be a vacuum, yeah? So, if you want to stop the conduction, you've gotta remove all the gas in there, you've gotta remove all the particles, ok?

EPISODE 6 (E#6; Y10.O1.P-Ch).

Ch.– So, Carlos, how is the heat reaching us from the Sun? because it's a long way away and it get here.

S1.– Ahm…

*Ch.– Tell me letters or say the word. Or **nominate someone else in your group**…*

S1.– Radiation.

Ch.– Radiation! Ok, thank you very much. It can't be conduction… Clemence, why is this?

S2.– Because there is nothing to conduct.

*Ch.– There's nothing to conduct. Ok. It can't be convection, either. **Why not?***

S2.– Because… there's not fluids…

Ch.– There's no fluid between us and the sun, yeah? Apart from a very, very thin layer, the atmosphere, there is nothing. So, there's nothing to conduct, nothing to convect. So, it's this process call radiation, ok?

EPISODE 7 (E#7; Y10.O2.P-Ch).

Ch.– Now, we're gonna do a demonstration of gases. So, there is a gas in this test tube, which is…

S1.– Air.

Ch.– Air. And that's a mixture, isn't it? What's in the mixture, Caroline? What gases are in the air?

S2.– Ahm, oxygen, …, ahm, can't remember.

Ch.– No problem. What is in there, apart from oxygen?

S3.– Nitrogen?

Ch.– Nitrogen. More than 80. And a little bit of…

S3.– Argon.

Ch.– Argon! And then, a little tinnier bit of…

S4.– Carbon dioxide.

Ch.– Ok

Ch.– Ok. Now, if we put that on there, and now, Claus, you now just put your hands on it, surround it, ok. Now, what's gonna happen as his hands… oh! You see that!? What did you see, Chan?

S5.– A bubble.

Ch.– So, Claus is making bubbles of here, ok? Did anyone see bubbles?

Ss.– Yes!

Ch.– Did anyone not see it? Everyone saw it, ok. Claus's hands may be a bit warmer than most, because he got sunburned today, but all of us, unless you are zombies or vampires, will have a body temperature of 37, which is warmer than the temperature in this room, which is approximately… 20, ok. So, try to draw a diagram, and then, try to explain that. ***Why are the bubbles coming out?*** *Draw the test tube, with the delivery tube and a thumb. Here is the test tube, with some liquid, and you saw bubbles coming up, ok, all right. So, the description of what happened is: 'hands, with a temperature of approximately 37 degrees, were holding a test tube. The delivery tube was in some water, and bubbles came out, ok?' just write that down. Just copy what I've done here. I can't draw, but, I mean, the test tube looks like that. 'A 37ºC-hand holds a test tube with a band and a delivery tube going into another test tube with water. Bubbles arise in the second test tube. And* ***the question is why?*** *So,* ***we're gonna ask you to write a little explanation.*** *What are the key words you need to include?*

S1.– Density.

Ch.– So, you have to include the word 'density', yeah. Anything else?

S2.– Expands.

Ch.– Expands.

S3.– Rise.

Ch.– Rise. Anything else, apart form 'expand', 'rise' and 'density'?

S1.– Oh, radiates.

Ch.– Your hand is in contact with it, isn't it? It's actually in contact. What's the kind of heat…

S1.– Conduction.

Ch.– Remember that radiation is when it's travelling through… so, when it's in contact, it's probably more a matter of conduction.

S1.– Ok.

Ch.– So, we can say 'conduction heat through the solid', and what else. Apart rom conduction. So, o., your heat is being conducted from your hand through the glass, into the air…

S4.– Convection.

Ch.– You got convection, it's a fluid, isn't it? If it's a fluid, you must have some convection going on. So, these are the words you could use: 'Density, expands, rise, conduction, convection… anything else? What about the word 'temperature'? yeah? Because there's a temperature difference. Ok, all right. So, quite a challenge, ahm, do you need to do a little bit of discussion before you do the writing? We've done a lot of thinking about it. We've done a lot of communicating about it. It is often better to communicate before you write. It's good to talk. Ok, stop copying. You can copy that later. What we're gonna do is to give you 45 seconds to discuss with your partner how and why that happens. Ad try to use these words. Purely and simply discuss. Your 45 seconds start now! Ok, ok. You had a chance to communicate, and now, it is the time to write. If you can, include *all these words (…). If not, it doesn't matter. Three minutes for writing. All we want is for you to write the explanation in three minutes, starting from now. (…). Ok, now read your answer to the person sitting next to you. And listen to his. So, take turns: one reads, one listen and then, swap. And then, potentially, if you listen to something that you say 'uh, I should include that', the, improve yours for a minute. So, read out loud taking turns. Ok, you listened, you read… can you improve your answer now? One minute. If you can improve your answer, please, do improve it. Ok, so, there we go.*

EPISODE 8 (E#8; Y9.O1.C-Ch).

Ch.– Now, the question is: ***why are they not all the same?*** *Yes? So, what we've got? My walk took the same amount of time, but they are all different. I mean, the only ones that are the same are these two, but nothing else is the same, isn't it? You have a whole minute to try to discuss why they are different.*

S1.– Possibly, because we didn't start at the same time and stop differently, too

Ch.– Yeah, absolutely right. Fantastic answer. Anything else, apart from that? So, different reaction, because start differently and stop differently. Or the devices could be wired differently, we calibrate them differently.

S2.– For the counting in head, it is not quite accurate. And, so, for the clock, because […].

Ch.– Yeah! It's a long way away, and the angle of the clock is very difficult to tell exactly what is the second, yes.

S1.– You don't count middle seconds in your head. And with the timer you can, so you have more accurate results.

Ch.– Yes. So, these ones are not the same level of accuracy as the timer on the mobile phone or that one. They are more accurate. They can give you 1/100 of a second.

EPISODE 9 (E#9; Y7.O2-Ch).

Ch. – Open your books at the lesson when you were doing the neutralisation, with that long thing burette, remember? Excellent. Ok. Now, the first question for you this morning is what were the names of the two chemicals that we were mixing? So, we got sodium hydroxide at the bottom, and that was one chemical, and then, there was a different chemical in the burette that you filled up. Can you remember the name? work in pairs in ten seconds, just to remember the names of these chemicals. Five seconds. 3, 2, 1. Who knows? Hands up! […] Perfect. The two names were hydrochloride acid and sodium hydroxide. And she even went to the formulas: HCl for chloride acid and NaOH for sodium hydroxide. Ok, very well done. Now, Cecile, of those two, HCl and NAOH, which is an acid, and which is an alkali?

S1.– HCL is the acid.

Ch.– Ok, and which one is the alkali?

S1.– NaOH.

Ch.– That's the formula, what's the name of the alkali?

S1.– Sodium hydroxide.

Ch.– Perfect, sodium hydroxide, very good. Ok, now, what do you think was the inmate? We know that the colour went from being purple to blue and eventually green, maybe even yellow. But, to get to neutral, what do you think was being made? Ten seconds, again, talk to your partner. What do you think was being made? 10 seconds! 5 seconds, ok, hands up!

S1.– Water?

Ch.– Hands up if you agree with that. If you think it's water. We have 4 people who agree, ok. Now, hands up if you disagree. Ok, you're very brave. Now, ***why do you***

disagree? *We put an indicator. The indicator, as you know, is something that changes it colour whether it's in an acid or in an alkali. Yeah? Remember we did our own cabbage indicator? And it changes colour depending on how acid or how alkali, or if it's neutral, changes colour. (…). There's no way of knowing when it's neutral. That's why you use the indicator. So,* ***why do you think we made water?*** *What makes you think that's a good answer?*

S1.– Water is one of the only neutral substances.

Ch.– Great answer! Very good, that's excellent.

S2.– Because if you have water you need hydrogen, which is H, and Hydroxide, which is HO, which is what makes something acid and what make something alkali… so, if you add and acid to an alkali to make it neutral, then, the H and the HO combine in H_2O.

Ch.– That is a great answer. That's a fantastic answer. He knows that water is H_2O, he knows that acids got H, he knows Hydroxide is OH. If you put H and OH together, you get H_2O. that's a great answer. Very, very good.

EPISODE 10 (E#10; Y10.O3.C-Ch).

Ch.– With the person next to you, ***why is it that increasing the temperature increases the rate of reaction?*** *30 seconds. (…). Charlie, the dice of destiny have chosen you to explain us why is that increasing temperature increases the rate of reaction.*

S1.– Ahm, because the particles are moving faster.

Ch.– Ok, so, the particles are moving faster, which should move to more collisions. Hands up if you agree with that. Ok, everyone agrees. Ok, that is a minor effect. There's something else with temperature that has a much bigger effect than just increasing the number of collisions.

S2.– I'm not sure, but, because there's more temperature, they have more energy to pass… so, because to make collisions successful for the reaction there has to be a certain amount of energy…

Ch.– Ok, let's talk about this again, right? So, if they miss each other, there is no chance of reaction. If they hit each other with not enough energy, they don't react. But if they hit with enough energy, they will react. Now, if a million collisions are required to give you one reaction, and you increase the temperature, what you would find is that a million collisions would probably lead to ten reactions. So, yes, there are more collisions, but it's not just because you double the number of collisions and you get two reactions. When you double the collisions, you get 20 reactions. Do you get the difference? The main difference is that they are moving faster, so, there is a higher proportion of collisions that has got enough energy to break bonds and to make bonds. Does it make sense? Yes? You're gonna write that down after the break. You're ***gonna write this explanation after break****.*

(…)

Ch.– Increasing the temperature increases the rate of reaction. ***Can you use colliding theory to explain it?*** *(…) Ok, so everybody else, apart from you, discussed this for about ten minutes this morning, so they should be able to write an answer now, ok? (…). You've got three minutes to write answers, ok? Three minutes. And the clock has started. You're gonna read up your answers to your partner, and then, they are gonna read theirs to you, and then, you're gonna see if you can improve your answer. But first, write your own answer. (…). Ok, guys, if you take in turns to read, listen, read, listen…, just to… did you write an answer?*

Ss.– No yet.

Ch.– No yet, ok. Try to use your own words if you can.

Ss.– Yes.

Ch.– Now, can you read and listen and then, take on board what your classmate says to see if you can improve your answer? (…). Ok, so, now, can you try to slightly improve *what you've written? We're gonna read a model answer, which is on page 111. (…). Here we go, page 111. We're gonna read out one word at a time, focus, one word. We're gonna star with Chris*

Students reading.– Using the collision theory. There are two ways you can explain of why increasing the temperature increases the rate of reaction. The second is the most important. When we heat up the reaction, the particles gain energy. When particles gain energy, they move faster. And collide more often. The frequency of collisions is increased. This results in an increase rate of reaction. In order to react, particles must gain a minimum amount of energy. This is called the reaction energy. As the temperature gets higher, more and more particles have this minimum amount of energy to react; in other words, as the temperature is increased, there is more chance of a collision between the reactant particles be successful. We say that that number of effective collisions in a given time increases as the temperature increases. Lower-temperatures particles have less energy, so they collide less frequently, and are not very effective. Higher-temperature particles have more energy. They move faster and collide more frequently. The collisions are very effective. Note that as the temperature increases, each particle collides with a greater force. It is also more accurate to say that there are more frequent collisions than just more collisions. (…). Now, we've got some questions for you to demonstrate what you've learnt so far about the rate of reactions.

EPISODE 11 (E#11; Y7.O2-Ch).

Ch. – Before you do, let's just think about it, let's make predictions. So, we know that nothing really happened with water. With vinegar, which is a weak acid, you get quite a lot fizzing, what shows that a gas is made. What's your prediction with HCl?

S1.– It will dissolve.

Ch.– Ok, will it dissolve? Maybe. Anything else? What else might happen?

S2.- Will it make some bubbles?

Ch.– How many people think is gonna make some bubbles? Ok, everyone, right? We think is gonna make some bubbles. Would it make more bubbles, or would it make less bubbles than vinegar?

S3.– I think it's gonna make more.

Ch.– ***And why would it make more?***

S3.– Because it's a stronger acid.

Ch.– It's a stronger acid, ok. Now, you are right on your prediction.

EPISODE 12 (E#1; Y10.O3.C-Ch).

S1.– ***Why is it one minus ($^-$)?***

S2.– Because it's a non-metal.

Ch.– Because it's a non-metal, and non-metals form negative ions. How many electrons are there in chlorine outer shell? Normally. Normally, how many. Which group is it in?

S1.– Seven.

Ch.– Seven electrons. So, when it gets one, it fills the outer shell.

EPISODE 13 (E#13; Y10.O3.C-Ch).

Ch.– In here it's just neutral. Can you see that? How do we now get dry pure crystals of sodium chloride? From this.

S1.– Filter.

Ch.– We don't need to filter anything! Not in this one. We did in the other one, because it was an insoluble base. There's no filtering needed. You need to gently heat it. ***Why are we gently heating it?***

S2.– To evaporate the water.

Ch.– To evaporate the water, exactly! That's what we're gonna do, right? So, you gently heat it, and then, you leave it on one side.

EPISODE 14 (E#14; Y8.O2-Ch).

Ch.– You're gonna put your ink in this line, ok? This line. (…). Ok, now, Cristine, when you put the paper in, what can you tell us about the water and the paper? What does the water do when it hits the paper? Does it stay exactly where it was?

S1.– ahm, no, it goes higher.

Ch.– It goes up. Does it go up?

S1.– Yes, yes.

Ch.– So, the water moves up the paper. Does the paper move up? Or it stays where it is?

S2.– No.

Ch.– The paper stays where it is. The water moves up the paper, that what's happening, right? Ok. Do you know that some things dissolve in water? Other things don't. How do we call something that dissolves in water?

S3.– Soluble.

Ch.– And if it doesn't dissolve is…

Ss.– Insoluble.

Ch.– Ok, now, ***why do you think you use the pencil line?***

S3.– Because water is insoluble.

Ch.– Water is insoluble?

S3.– No! pencil is insoluble.

Ch.– Pencil is insoluble, that's fine, yeah. Pencil is made of graphite, isn't it? Not lead, it's graphite. And it's insoluble. So, will it move with the water?

Ss.– No.

Ch.– No! because it doesn't dissolve. No, these inks that are moving, what do you know about them? Are they soluble or are they insoluble?

S1.– Insoluble.

Ch.– So, they don't dissolve.

S1.– Yes.

Ch.– But, if they are insoluble, they will stay where they are.

S1.– They're soluble.

Ch.– They're soluble because they are moving with the water, right? The pencil stays where it is, but the inks move. So, they are soluble, fair enough? Make sense? Ok. Now, can you see that, in some of these inks there's more that one [inaudible] compound? There's more than one substance in there? Can you see that?

Ss.– Yes.

Ch.– And they get separate! ***Now, why are they getting separated? Why would they possibly get separated?*** *So, for instance, you might be seeing yellow and blue out of your black ink. So, why would they might be separating? They are all moving! The yellow is soluble. The black is so…, sorry, the blue is soluble, but why are they being separated?*

S4.– It might be because some of the chemical are soluble, and some are insoluble.

Ch.– Well, they are all moving, so, all of those chemicals in that ink are soluble. So, why are they moving at different speeds? Why are they moving at different speeds in terms of solubility?

S1.– Because of the acidity…?

Ch.– No acids at all. What we are talking about is whether something or not something dissolves in water. If it dissolves in water, is moving with the water. Have a look! Are the inks moving as fast as the water?

S1.– No. (…)

Ch.– No necessarily. Some of them are, but the others are not, are they? So, here you've got yellow is a long way behind the water, isn't it? So, why are they separating in terms of solubility? Why is the yellow… so, here, you've got yellow here, but up here you've got blue bits… the water's got to here, right? The blue is… why is it that the yellow is gone less far than the blue, in terms of solubility? Are they soluble in water?

S4.– Yes.

Ch.– Are they the same solubility?

Ss.– No.

Ch.– Which is more soluble?

S2.– The blue.

Ch.– Yes! So, what we're talking about is separating thing that are less or more soluble. Fair enough?

Ss– Yes!

Ch.– So, that's why it's a separating technique. You are separating here certain parts of the ink that are more soluble than others. Make sense? You can use it to identify things.

EPISODE 15 (E#15; Y10.O2.P-Ch).

Ch.– So, if you got this bulb, and inside the bulb there's this very large amount of liquid, ok? I'm just gonna colour it in red here. Most of these thermometers have alcohol in them, because alcohol, as phenol, is pure and clear transparent, which is not good, isn't it? So, they put a little bit of dye to make sure you can see it. In those one, it's kind of green. That one you've got is mercury. Now, this liquid is expanding as your hands are around it. But the bulb is also expanding, because solids also expand. What's the difference between the way the glass is expanding…?

S1.– It's slower.

Ch.– So, it's expanding less, isn't it?

Ss.- Yes.

Ch.- So, in solids, they stay in fixed positions, they are vibrating more, it takes more space, the particles, to make them up, so the solid, it expands, but not as much as the liquids. Does it make sense?

Ss.– Yes.

Ch.– Ok. So, that's the first thing. Now, ***why is it that we have a very, very thing glass tube inside?***

S1– To make it more accurate.

S2.– So, the heat goes directly to the…

Ch.– So, how did it different if we had that, and that, and the bulb here was like that?

S3.– It would take longer.

Ch.– What would it take longer?

S3.– The liquid to raise.

Ch.– So, let's just say we've got a liquid in there, ok? And your hands go on at 37 degrees; what would happen here? What would happen here? Discuss to the person close to you, *30 seconds. Ok, guys, what did you get? (…) Claire, what would be different between these two?*

S4.- I think the thinner would raise faster, because it takes less energy to heat it up.

Ch.- Hands up if you agree with everything that Claire said. (…). Not pretty sure about it, ok. This is what it happens in reality. The diameter of this one is much bigger. Just imagine it is the same size. So, overall, the expansion is, let's say, 2mm^3, right? 2mm^3 in a thin tube is a big difference, whereas in the big one, is not. So, here, you will have to have 20, 21, 22, 23… that will be the difference between 20 and 37, whereas here, you could have that as the difference between 20 and 37. And you can have a lot more spaces and, as Claude. said, it would be more accurate, wouldn't it? Makes sense?

Ss.- Yes.

Ch.- Ok.

EPISODE 16 (E#16; Y0.O3.C-Ch).

S1.– ***Why is ammonia so bad smelly?***

Ch.– I don't know that answer. Obviously, it is interacting, isn't it? With your…, your sensory glands in your nose, in that area… I have no idea, no idea. The whole science of smell is a mystery to me, to be honest with you.

A.8. ALBA'S CASE

ALBA	YEAR 9	YEAR 11
CLASSES	3 hours/week	3 hours/week/group
No. OF GROUPS	1 (Sp)	2 (Sp, [Fr])
No. STUDENTS/GROUP	25	32, 30
No. OBSERVED LESSONS/GROUP	6	11
TOPICS	Hooke's Law; Gravity force; Electrical force	Describing motion
EXPLANATORY EPISODES	9	6

Table A.8) Details about Alba's observed lessons.

A.8.1. Description of classroom context and teaching

Alba is a science teacher whose teaching experience spans a total of six years, shut off by two maternity leaves. After completing her degree in Chemistry and a master's degree in Education, Alba took the examination to access the public education system in Madrid (Spain). Although she passed the exam, she did not get a tenure position, so for four years, she was rotating through different schools. In 2016, Alba sat the public examination again, and this time she managed to get a teaching position in School-A. Alba says this rough path served her to confirm teaching as her passion; she confesses to genuinely enjoying working with high-school students.

Although Alba feels confident about her content knowledge of the subjects she teaches (which includes Physics, Chemistry and Mathematics, in both Spanish and French), she is aware she has some knowledge gaps. Alba is quite honest in this respect with the students – "*I'm sorry to tell you that your (..) teacher does not know everything. Partly because of my ignorance, and partly because we don't know everything*" (Y9.O4-Al). She even receives with enthusiasm that a student corrects something wrong she has said *–Al.- I have never seen a spherical magnet. S2.- The Earth is a spherical magnet. Al.- Oh, you're right! Yes, very well*! (Y9.O5-Al). Alba also recognises that she is "*quite messy when it comes to delivering content knowledge*" (I-Al), something that students sometimes complain about. She assures that she tries to compensate her disorganisation with the passion she puts into what she does; so much so that Alba characterises herself as "*a circus artist*", meaning that she is "*quite good at staging to attract students' attention, and juggling with language to explain the same thing in many different ways*" (I-Al).

When asked about her current workplace, Alba is also quite enthusiastic. She describes it as "*a very lively school"*, with a *"friendly environment"* where teachers have "*a high degree of freedom to propose learning activities*" (I-Al). The year of my observations was the first time the Science Department of the school had managed to agree on a common syllabus, as well as the assessment criteria and a work plan for the laboratory. Alba says to be very proud of these achievements. However, she believes that teachers need much more training to really know how to coordinate and work as a team. This training would facilitate, she says, the inclusion of a project-based learning approach, of which Alba avows being a true admirer. She regrets that all her attempts to introduce this approach in the classroom have been unsuccessful; she is convinced that this is because i) teachers are not prepared for the degree of involvement and coordination that working by projects requires; ii) the pressure of covering the whole list of curricular topics is too high; iii) this approach works better with small-ratio groups; and iv) students are not accustomed to work by projects.

These, among other reasons, make Alba choose a didactic approach for her instruction, where activities and lab work are preceded by lectures exposing the students to the content. In this delivering-based methodology, Alba believes to have the responsibility to help students understand. Students' role, then, is limited to attending her explanations based on PowerPoint slides, answering questions, raising doubts, solving drill-practice applications, and checking them collectively on the board. To gauge the impact that this working scheme has on students' learning, Alba constantly questions them; the posed questions aim at probing whether they follow the explications and do understand what is being done. In the classroom, Alba works on this scheme with hardly any changes, but in the laboratory sessions, it is profoundly modified. The few times they manage to go to the laboratory, students work in small groups (because of the number of spots) and have the freedom to move and talk. Alba does not give them lab recipes telling what to do, but she provides very rough guidelines and let them experience on their own – "[d]*on't ask me, pretend I'm not here*" (Y11.O4-Al).

Alba follows to the letter the guidelines set by the Science Department in terms of the content to be taught and how to assess it. Thus, the objectives for the science course almost exclusively focus on the acquisition of conceptual content and the development of mathematical skills to solve standard numerical problems, although this is not openly admitted by Alba. Something also very characteristic in her teaching practice is the emphasis she puts on her students to learn how to interpret graphs and solve the problems graphically –"*This is the first year in which everyone knows how to draw graphs much better than solving equations. That makes life easier for you"* (Y9.O9-Al).

In her classes, Alba also provides some insights into the Nature of Science (NOS) and the values of professional practices, albeit to a much lesser extent. For instance, she makes explicit mention of practical aspects of science (e.g., measurements errors) and social aspects (e.g., the need to conform to certain rules when communicating scientific results). These examples, though, correspond to isolated events which, not being accompanied by engagement in authentic disciplinary practices, would not have much impact among the students.

When asked in the interview for her main objectives as a science teacher, Alba said there are three things she would like students to take from her classes: i) that curiosity can help people get to know the reasons for almost everything; ii) that by hard-working, everyone can achieve their goals, no matter how much time it requires; and iii) that science surrounds us. The latter is the only one for which I could find some piece of evidence in her practice. It relates to another of Alba's intended targets, which is "*to bring the goals of the subject closer to [students] daily objectives and interests"* (I-Al). Alba is convinced that this could trigger students' motivation, which, in turn, would lead to deeper learning. In line with this target, Alba uses numerous everyday examples in her explications.

Alba admits she would like to achieve a higher degree of students' engagement in their own learning; to use "*the constructivist approach"* (I-Al). When she plans a lesson, she takes students' knowledge as the starting point. However, when it comes to bringing the constructivist approach into a real context, she finds some obstacles: i) The ratios. Alba advocates for groups smaller than those allowed by the Spanish educational system; ii) The curriculum. For Alba, the main problem is not its extension, but how disconnected it is from students interests and needs; and iii) Teachers' education. Alba does not feel well prepared for adopting this approach. She says the learning environments in which she was enculturated do not share constructivism' basic principles; and in the absence of training and experience, it is easier for her to repeat the already known patterns than to investigate new ones.

> *"I think that when you want to become a teacher, you would love it to be that way, of course you do, and in part you try. But (…) we need training to be able to deliver a lesson in a way that is not lecture-based. Because what we have experienced is lecture-based learning environments. So, it is very difficult to do something different from what you have experienced for years" (I-Al).*

When I questioned Alba about the dimension of learning that she was most interested in assessing, she declared it to be "*student's effort*". The problem, she thinks, is that this requires time. She referred to observations to exemplify this. Alba sometimes conducts informal observations on students' homework. And although in these cases she only checks whether the task has been done, it takes "*15-20 minutes, which is half of a class*", and therefore, for her "*it is not worth it*" (I-Al).

Alba's main tool for formal assessment is paper-based exams. She usually prepares two exams per term. In them, she only includes numerical calculation questions which do not require students to use higher-order thinking – *"[We don't ask the students to] reason… well, the reasoning is purely logical-mathematical*" (I-Al). Alba concedes that the rationale for this is simply pragmatic:

> *"[T]hat's for the convenience of the teaching staff. There are many exams, and we have very little time to mark them; then, the argumentative questions are left to the Humanities [teachers]. And we avoid that kind of questions in an exam, to avoid…, to avoid having to assess more than three lines per question"* (I-Al).

Alba's assessment system is guided, then, by institutional guidelines for accountability. The latter include, as we saw on Adrian's profile, the recognition of students' participation in both class and lab activities, and some oral presentations.

A.8.2. Alba's PCK of Scientific Explanation. Introduction

In the next sections, I introduce the results of the analysis of the data collected from Alba, in an attempt to depict what she knows about scientific explanation, what she knows about *what* to teach (and assess) about this practice, and what she knows about *how* to teach (and assess) it (Loughran *et al.*, 2004). This information is summarised in Table A.8.2.a.

ALBA			
Orientation Toward Science (OTS)			
Knowledge/beliefs about the goals of science	Knowledge/beliefs about science teaching and learning	Teaching practice	Knowledge/beliefs about Scientific explanation
· Science as a way of apprehending reality. · Observation as the origin of scientific knowledge. · Scientists as explanation seekers.	· Self-defined as constructivist (aspiration) · Didactic teaching orientation · Recognised objectives: Foster curiosity; Promote hard working; Remark that science surrounds us · Importance of motivation · Importance of connecting goals and interests	·Tries to find a balance between teacher-centred (experience) and student-centred (beliefs) → Didactic instructional strategies · Focus: content and mathematical skills · Lack of opportunities to engage in disciplinary practices · Low rate of student participation	· Looking for explanations is a fundamental goal · In the interview: Explanation as explication · In her practice: assortment of meanings (Explanations and Justifications)
Knowledge of Instructional Strategies (KIS)			
Communicative approaches	Activities	Language devices	Interaction patterns
·Interactive/ Authoritative (11) · Non-interactive/ Authoritative (3)	· Didactic · Exercise checking · No activities whose goal is to construct the explanation.	· Questions · · References · Requests/Invitations · Repetitions · Checks understanding · Changes/Constrictions in direction · Encouraging remarks	· Student's question – Teacher's answer · Teacher's question – teacher's answer · Alternation with interruptions · IRF
Knowledge of Assessment (KAs)			
Dimensions to Assess		Methods	
· Content acquisition · Lab work, presentations · Students' participation in class activities · Student's effort (aspiration)		· No specific model/instrument to assess students' ability to construct explanations · Informal assessment	

Table A.8.2.a) Summary of Alba's PCK of scientific explanation.

To illustrate the kind of episodes I witnessed in Alba's lessons, I show in Table A.8.2.b the most enlightening one.

TEACHER	***ALBA***
VIGNETTE/EPISODE/OBSERVATION	***V#1 / E#6/ Y9.O6-Al***
TOPIC	***Gravitational field***
S1.- Teacher, what about, for example, the Earth and Uranus…? The Earth compared to Uranus. *Al.- Uranus is bigger, isn't it?* *S1.- Sure.* *Al.- Then, it has a greater gravitational field.* *S1.- So…,* ***that's why it is farther?*** *Al.-No, Gosh! Because... no, but, uh ..., it means that ..., to see, eh ..., the force of attraction is smaller and that's why it [Uranus] is farther away. And what does happen is that the orbit is larger, it [Uranus] is at a greater distance. But it [the Sun] is able to attract it [Uranus], because its mass is larger than ours. Under the same circumstances the Earth, at that distance, since it is smaller, would not turn*	

around the Sun. Maybe, right? That is, it depends on the masses and depends on the distances. Can larger planets be attracted farther? Yes, because the force is bigger (…). In the same way, the Earth, due to the size that it has and the mass it has, could not be in Uranus' place. I do not know, OK? I haven't done the calculation. But it can be calculated, and maybe it escapes because it [the Earth] does not have enough mass to be attracted by the Sun.

S1.- But I do not understand it, because, for example, Jupiter is much bigger than Earth, then it should be closer to the Sun.

Al.- Uh, no. ***Why?***

S1.- Because… because it has more mass, then, it is more strongly attracted.

Al.- Yes. But it's farther. The strength depends on mass as well as distance. Then, it has more mass, the force is bigger. But it is further away, the force is smaller. Then, in that balance between mass and…, and distance, at that point it is in which it manages to rotate. if it were closer, maybe it would fall on the Sun. And if it were farther, maybe it would not turn around the Sun. It is at the point where the force is in balance so that, with its speed, it can continue turning and neither escape nor fall, okay?

S1.- Then, Pluto when it was a planet, how did it orbit? Because if it's so far away, and it's small...

Al.- Well, uh ... even if it's small, it's still very dense. That is, Pluto has a lot of stuff in there. I do not know the density of Pluto, but it is a very good question... If it orbits, it is because there is a force that is in balance. That is to say, with the speed at which it goes and the force that exists, it is attracted by the Sun, so it must be dense, it must have enough mass to be attracted by the Sun. Otherwise, it would escape. It would not turn around (…)

*S2****.- Then, teacher, if the Sun attracts the Earth so strongly, why does the Moon revolve around the Earth and not the Sun?***

Al.- Because it is closer.

S2.-Yes, I know, but…

Al.- The strength depends on the masses and the distance. And you are seeing that distance is also important. Because, in fact, it's true, the Sun is much bigger than the Earth. And it exerts a gravity on the Moon. But as the Moon is closer to the Earth, it is the action of Earth's gravity that prevails in that movement. In fact, the tides… have you studied the tides yet?

S3.- Yes, last year.

Al.- Why are the tides produced?

S4.- By the Moon.

Al.- By the Moon's gravity, right? But by the gravity of the Sun too. Do you know that there are spring tides and neap tides?

Al.- They are all tides, but we call 'spring' to those which are very strong. That is to say, there are many meters of difference between the low tide and the high tide, and the neap tides are those in which there are less differences. ***Why does that exist?*** *Because when just the gravity of the Sun and the gravity of the Moon pull towards the same place, the tide is a spring tide. That is, the Sun's gravity acts on the body of water. The Moon has more influence for being closer, but the Sun too, because it is very big, okay?*

Table A.8.2.b) Vignette #1. Example of explanatory episode in Becca's observed lessons.

A.8.3. Orientation Towards Science (OTS): Alba's knowledge and beliefs about Scientific Explanation

We have seen that Alba is passionate about teaching and she enjoys sharing her love for science with her students. It should not be surprising, then, that when asked what science is for her, Alba responded:

> *"Everything. For me, Science is everything; it is a way of life. I mean, I think people who are scientists see life in a very different way from the one who is an artist, or who is a philologist. For me, it's that. It is a way of life. And to observe everything around and trying to explain why."* (I-Al)

There are two things to highlight about this response: i) Alba identifies being a scientist with a way of apprehending reality; ii) Alba includes the search for explanations as one main feature of the scientific practice. It should be reminded that, although the participants were roughly informed that my research objectives were related to their teaching strategies and assessment methods, they did not know that my main interest was the construction of scientific explanations. Thus, we can think that Alba genuinely considers there is a key relationship between science and explanations. This affirmation is reinforced when she adds that what characterises scientists is their "*eternal search for whys*" (I-Al).

As a training scientist, Alba is convinced that "[her] *way of living is scientific*", and this is something she cannot conceal when she enters the classroom. Therefore, the way she understands science has an enormous impact on the way she teaches science, she opines. Alba would love to teach her students to think and act like scientists, but she believes this is difficult for two reasons:

i) the lack of time. Alba professes that the most she can aspire to do in the classroom so that students somehow emulate the work of scientists is to propose an observation for them to outline some testable hypothesis. The problem lies in the first step, that is, the planning and proposal of observations, since: "*teachers must wrack their brains to find things that call students' attention, to awaken certain inquisitiveness on them, a desire to know, and well, that it does not fade over time*" (I-Al). This way of working "*through observations that arouse some interest and the search for answers*" may be Alba's ideal way of teaching science, but it is not her actual way of teaching. The tension between the desired, and what can actually be performed in the classroom is a constant in Alba's practice; and

ii) the demarcation boundary between academic life and daily life that most students draw. This makes it even more difficult for they to integrate a scientific way of thinking and acting beyond the classroom. It is interesting to note that, in this except, Alba admits that learning science by doing would be effective for many students, which indicates this is not how she currently teaches science.

> *"It is as if they entered an island at 8:30 AM and leave that island at 3:30 PM. (…). Probably, if we taught science by doing science, then, it would be different*

for many students…but not for most, no matter how much we promote it here; there is a huge separation between School and the rest of their life" (I-Al).

When asked about scientific explanation, Alba proclaims she tries to promote students' proficiency in explaining things, but either for fear of expressing their ideas or for lack of vocabulary and communication techniques, "*students' responses (…) are disastrous*." Alba believes these deficiencies cannot be solved in the classroom: "*It is the parents who must encourage their children to read and have conversations*" for them to acquire and develop the necessary skills "*to properly express in the classroom*" (I-Al).

This drift in her answers led me think that perhaps Alba and I were understanding by 'explanation' different things; this impression was confirmed when she added that "*where we most encourage them to explain is in the laboratory-reports and their presentations, in which we ask them 'explain what you have done'*" (I-Al). From this answer, it seems that Alba uses 'explanation' as a synonym of 'rich description'. After transcribing my fieldwork data, I found 15 episodes in which Alba poses a why-question or demands an explanation; surprisingly, in none of them, she utilises the term with the meaning she refers to in the interview.

Alba's use of the word 'explain' can be summarised in two: 'justify' and 'account for a phenomenon' (see Table A.8.3.). Explanations from the second group can be codified as 'scientific'; among them, we find two variants: causal explanation –in which Alba looks for causal chains to explain why something is the case (E#9-Al)– and what I have called 'phenomenological explanation' –in which Alba justifies the existence of a phenomenon appealing to our experience (E#14-Al). Alba is the only participant in which this meaning appears.

On the other hand, the kind of non-scientific explanation Alba uses are justifications, which consist of providing the reasons that support responses/actions (E#15-Al) or mathematical conventions (E#1-Al).

TYPE OF EXPLANATION	***EXAMPLE***
SCIENTIFIC EXPLANATION	**Articulation of theoretical and empirical knowledge to make sense of a certain phenomenon through a process of reasoning**
Causal	*S1.- If the Sun attracts the planets, and all that, and the Earth, the vector field ..., if you do so, the pen falls ... then, why does the Sun not attract the Earth, like…?* *Al.-* ***Why don't we crash into the Sun? Because we have a speed.*** *There is a speed. Remember when we saw the forces and saw the effects they could produce. One of them was the carousel with the swings. The carousel was spinning. And there was a force that pulled them towards the centre to always*

	change their direction, right? ***Why doesn't that force make them crash into the central column of the carousel? Because they have a speed****. If, suddenly, that stops, of course, everyone would crash with each other. But as long as you have a speed, that force is not able to take you to the centre. It changes the direction and that's why you turn, but you cannot change…, cannot decrease that distance, okay?* (E#7; Y9.O6-Al)
Phenomenological	*Al.- There are two zones on the same magnet. And what happens if we cut the magnet? Does it exist a North pole alone and a South pole alone?* *Ss.- No.* *Al.- No* ***S1.- Why not?*** ***Al.- Because that's what experience says****. If I break this magnet in two pieces, one of the pieces is going to attract the other one, the other part is going to repel it. There are always the two poles in the magnet.* (E#14. Y9.O5-Al)
JUSTIFICATORY EXPLANATION	**Reasons (beliefs, norms, principles or codes) that favour and guide an action or an idea**
Justify a mathematical convention	*S1.-* ***Why does it have a minus sign?*** *[referring to the law Alba has written on the whiteboard: F=-k·Δx]* *Al.- The other day, when we reviewed Hooke's Law and saw Newton's law, I told you that, in Hooke's law, this force is exerted by the spring. But here, we are not measuring what [force] the spring exerts, we are measuring what [force] we apply. The spring exerts a force against. As it goes against stretch, it has a minus. (E#1; Y9.O2-Al)*
Justify an answer	***Al.- Is this affirmation true or false?: 'The deformations are equal to the deforming forces'.*** ***S1.- False.*** ***Al.- OK, why is it false? What is deformation?*** *S1.- When an object is deformed.* *Al.- Now, give me an example. Give me an example in which, if you tell me it's false, they're different, right? Give me an example and tell me, define them...* *S1.- A rubber band, when we stretch it, it will...* *Al.- OK, and what's the deforming force?* *S1.- The force you make to deform the rubber.* *Al.- That's it, it's okay. In Hooke's law, the deforming force would be F; and the deformation, what would it be?* *S2.- The elongation.* *Al.- The elongation, that is. Very well!* (E#3; Y9.O3-Al)

Table A.8.3) Alba's different meanings for 'explanation'.

Although in her classes, she used these meanings consistently, in the interview, she did not refer to them. This makes it difficult to know whether Alba has a discernible notion of what it means to construct a scientific explanation in the sense curricula and reform documents allude (Duschl, *et al*., 2007; MECD, 2013; OECD, 2017). In another moment, Alba affirms: "[w]*ell, I am a teacher, I like explaining*", which seems to mean that she likes explicating as I understand it in this thesis. Throughout the interview, she delves into this meaning, unravelling how she produces an explanation:

> *"To explain something well, you have to organise your ideas; that is, you have to do a lot of previous work. But it is not something that I find difficult. The first thing I do is writing down all the ideas. Secondly, I put them in order. And, third, I use the appropriate connectors. And with that, I build my explanation."* (I-Al)

Interestingly, for Alba, the production of an explanation is a process, something that requires selecting and organising information. This approaches my conceptualisation of explanation as-a-practice. She believes that building explanations (as she understands it) could help students deepen their knowledge comprehension, as well as improve their technical vocabulary. That is, Alba connects explanation production with the usage of language in a specific way, which also connects with my operational definition of scientific explanation. Alba adds that acquiring the ability to explain could help students develop their critical-thinking skills, albeit "*in the long term*" (I-Al).

In Alba's lessons, I could not find activities targeted at learning how to construct explanations. Alba used explanations as means to achieve other goals; usually, to present/strengthen an idea/concept/law (e.g., that velocity is tangent to an object trajectory (E#13-Al), or that gravity is a weak force (E#5-Al)). This might be one of the reasons why she never addresses what explanations are and how to build them.

Alba is not always who initiates an explanatory episode; five of the 15 selected episodes are triggered by students. The strategies Alba uses to develop the explanation are the same in both cases, though. However, when Alba tries to explain a phenomenon proposed by a student, her accounts contain many more conceptual errors. It is not uncommon for her to end-up recognising she does not know the answer:

> *S1.- Miss… the Sun burns atoms to keep on burning, right? If it has already been burning for billions of years,* ***why doesn't it turn off?***
>
> *Al.- Because…, it's a bit complicated for you to understand, but basically because, although it's true that it's a big ball of Helium, Hydrogen...*
>
> *S1.- Wouldn't they burn completely and that's all?*
>
> *Al.- No, because, they burn…, well, they burn ..., it is that for you to burn is 'to be destroyed'…*
>
> *S1.- To combust.*

Al.- Not here. Here 'to burn' is to get separated, or lose electrons, or ..., then, when they move away and cool down, then they recombine again; and then, due to gravity, they return ... it's like a cycle.

S1.- And when is it going to turn off?

Al.- It's going to turn off, but I do not know if we know. Well, within millions of years. (E#8-Al).

Examples like this reflect that students are not the only ones who encounter difficulties to elaborate good scientific explanations. So, this is a practice in which much more emphasis should be put, both in the science classroom and in the teaching training programmes.

A.8.4. Alba's Knowledge of Instructional Strategies (KIS)

As described above, Alba's teaching style can be summarised as a delivering method, seasoned with probing questions to gauge learners' knowledge. Since Alba follows the dictates of the Science Department about learning objectives, content, and assessment, her teaching focuses on conceptual knowledge, despite not being what she would prefer. It is not surprising, then, that the most repeated communicative approach among the 15 episodes analysed is Authoritative; 14 in total. That is, when engaged in explaining, Alba's main purpose is to lead students to the so-considered canonical view. On 11 occasions, this is done within the flow of discursive interactions, in response to participants' shares, so they are classified as Interactive/ Authoritative. On the other three, the interactive character is lost: Alba exposes a single perspective, excluding any chance for students' participation. These are classified as Non-Interactive/Authoritative (Table A.8.4.a).

COMMUNICATIVE APPROACH	EPISODES	EVIDENCE
Interactive/ Authoritative	1; 3; 4; 6; 7; 8; 9; 10; 13; 14; 15	*Al.- Let's see the car example. We have the force of the motor which propels it forward; that's why it moves, isn't it? And the wheels? Because the engine may propel it, but, cars, carts, all these things move with wheels, right?* ***What is it that turns the wheels?*** ***S1.- The motor.*** ***Al.- Well, Ok, but when a car skids, when there is mud, when there is ice, the wheels slide, they do not spin. What does really make the wheels spin? It's the friction with the ground, okay?*** *Then, the friction goes in the opposite direction. Because when the car moves towards that direction, the wheel does like this; then, the friction force is what pulls the wheel down, okay? There's almost no friction on ice ... Why do they use blades [referring to skaters]? if there is no friction, they could skate with their feet, couldn't they?*

		S2.- Yes. *Al.- But they could not stop! If there is no friction, how could they stop? They would land on their butts, and even so, they keep ..., right? So, they need blades, because when they want to brake or turn, and not to fall, eh…, they need to drive the blades into the ice to be able to stop, okay?* (E#4; Y9.O4-Al)
Interactive/ Dialogic	----------	----------
Non-interactive/ Authoritative	2; 5; 12	*"When we talked about curves, some time ago, we said that the velocity is tangent to the trajectory. And it was you, one day that we were talking about that, who told me that if we were spinning in a carousel with swings, we would be shot off.* ***Why? Because if we were stopped being pulled towards the centre, then we would follow the velocity vector that we had at that moment.*** *(...) It was you who said that, and I loved it, because it was not something that I proposed to you, the idea came out from you"* (E#12; Y11.O11-Al)
Non-interactive/ Dialogic	----------	----------
Non-classifiable	11	*Some try to explain why the doors fail [**"Maybe it's the metal that does not detect it"**]. They look for causes spontaneously; she does not ask them that.* (FN. Y11.O4-Al)

Table A.8.4.a) Alba's communicative approach for the episodes on explanation

Alba's explanatory episodes are framed within different types of activities, none of them purposely planned to teach students how to build scientific explanations. Alba usually engages in cycles of instructional explications with examples to provide students with the knowledge she deems necessary to understand the topics; 11 of the 15 episodes follow this pattern. The actions inserted in these cycles consist of follow-up and reinforcement interventions in which the students remain quite passive. Only three activities are of a different type (E#3-Al; E#10-Al; E#11-Al), involving students more actively. Table A.8.4.b displays examples of Alba's activities.

TYPE OF ACTIVITY	EXAMPLES
Didactic (Teacher-student interaction)	*Al.- I ask you, does this line that you have put here have a positive or negative slope?* *Ss.- Positive.* *Al.- The equation, positive; but the line that we have drawn, can you see that it goes down? The slope has to be negative. Can everyone see that? Well; then, you put a minus here at the front.* ***Why?*** *Because it goes against what we have marked in the position. The position grows up, right? And this goes down.* *S1.- But is it just to get it right, or ...?* *Al.-Yes, sure. That minus does not mean that ... let's see, it only makes physical sense.* (E#10; Y11.O1-Al)
Communal problem solving (Teacher-student interaction)	*Al.- Is this affirmation true or false?: 'The deformations are equal to the deforming forces'.* *S1.- False.* *Al.-* ***OK, why is it false?*** *What is deformation?* *S1.- When an object is deformed.*

	Al.- Now, give me an example. Give me an example in which, if you tell me it's false, they're different, right? Give me an example and tell me, define them... *S1.- A rubber band, when we stretch it, it will...* *Al.- OK, and what's the deforming force?* *S1.- The force you make to deform the rubber.* *Al.- That's it, it's okay. In Hooke's law, the deforming force would be F; and the deformation, what would it be?* *S2.- The elongation.* *Al.- The elongation, that is. Very well!* (E#3; Y9.O3-Al)
Laboratory Activity (Student-student interaction)	Some try to explain why the doors fail [S1.- *"Maybe it's the metal that does not detect it"].* They look for causes spontaneously; she does not ask them that. (E-FN; Y11.O4-Al)

Table A.8.4.b) Types of activities present in Alba's episodes on explanation.

To analyse Alba's communicative moves when constructing explanations, I followed the coding scheme I developed from Kaartinen and Kumpulainen (2002), the SEDA framework (Hennessy *et al.,* 2016), and the Tutor Dialogue Move Coding Scheme (Lehman *et al.*, 2012) (§3.7.2). Within her explanatory episodes, I found evidence of the following discourse moves: Initiating, Extending, Continuing, Referring-back, Replying, Commenting and Concluding moves (Tables A.8.4.c). Codifying Alba's explanatory episodes was quite complicated. In practically all the interventions, it is Alba who develops the whole explanation, and the discourse moves she used to engage the students in the process seemed, in many cases, irrelevant for the final product. Thus, although Alba employed different strategies to monitor their understanding and to elicit some students' ideas, these were not pursued as necessary for the explanation. Alba, then, selects and/or reshapes them to fit her own narrative.

Explanatory episodes usually start with Alba launching a question about an aspect of her presentation she wants the students to understand. For example, in three episodes, Alba asks about the result of a mathematical problem –why the slope of a graph is negative (E#19-Al), why the line drawn by Excel has no y-interception (E#2-Al), or why the number of significant figures is two (E#15-Al). This last episode is singular, because it is, together with Episode #3, the only one in which Alba addresses a specific student to answer, instead of throwing the question to the whole class. More usual is what happens in the other two examples, in which Alba provides her explanation without even giving the students any time to think their answer.

I find it interesting those episodes where a student triggers the explanation-building process with a question, because they are an expression of curiosity, of a desire to know. Alba could have used these interventions to initiate authentic dialogical exchanges, where the students present their ideas to arrive together to an agreed explanation, but this is not what I observed. The questions the students pose –*Why does a black hole attracts us? Why don't we* *crash into the Sun?* (E#6-Al)– are intended to connect what they learn in the classroom with their knowledge about the world; this would refute what Alba reported in her interview.

Regarding the communicative acts that Alba performs once the process of constructing the explanation begins, we see that many of the student-addressing questions aim to monitor their comprehension –*Right? OK? Understood? Does everyone have that in their mind?*–. Alba usually settles for gestural confirmation –e.g., a nod– but sometimes she demands explicitness –"*Does everybody understand what I say? Ask me! Ask me! Why don't you ask me when you do not understand?"* (Y9.O5-Al). A more direct way of engaging students consists of posing probe questions, demanding some examples, justifications, definitions, and/or clarifications. If the student involved is not able to respond, Alba asks another student. Only during Episode #6 (the most complete and relevant that I observed), when a student asks why Jupiter, being bigger than Earth, is not closer to the Sun, Alba asks him back why he thinks that should be the case, and gives some time for the student to put his ideas in order.

As stated above, Alba's dominant approach to classroom dialogue is Authoritative. That is, her explanatory interventions are based on instructional questions for which she has in mind one particular answer. In line with this approach, Alba displays a wide variety of moves to lead and redirect students along the stipulated path. We find examples of paraphrases, rhetorical questioning, and contributions that are ignored. Due to this, students' interventions are limited to brief assertions made in response to Alba's questions. She occasionally responds to these contributions by making encouraging/reinforcing comments. Given that the main objective of Alba in the analysed episodes seems to be that the students understand a concept in-depth, she occasionally refers to prior explications or students' prior knowledge. This fits within her self-assigned constructivist conception of learning. Alba also tries to establish connections with other topics on the syllabus. Very interesting, too, is her reference to practical aspects of the scientific enterprise, which is consistent with the teaching goals I noted on Alba's practice (§A.8.1).

Most of Alba's episodes do not conclude categorically (see, for example, E#13-Al). This might be because, as said before, these episodes are not part of activities that are an end in themselves. Only one episode finishes with Alba summarising what she has explained, which supports the idea that these are not self-contained episodes. Somewhat different are Episodes 6, 7, 8 and 9, all of which take place in the same session (Y9.O6-Al). These episodes begin with a student's question. And all finish with Alba trying to terminate the explanation to change the topic. Once an episode concludes, Alba does not refer to it at any later point, so they are completely isolated from the rest of the lesson.

Table A.8.4.c) Discourse moves present in Alba's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy* et al., 2016*), and Kaartinen and Kumpulainen (2002).

ALBA'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Initiating moves	Student's question	*S1.- If the Sun attracts the planets, and all that, and the Earth, the vector field ..., if you do so, the pen falls ... then,* ***why does the Sun not attract the Earth, like…?*** *Al.- Why don't we crash into the Sun? Because we have a speed.* (E#7; Y9.O6-Al)
	Rhetorical question	***Al.- There's no n here, right?*** [referring to the y-intercept] **Why?** *Because more or less, it has to be zero. And almost everyone got that. You have obtained 'zero, comma, zero something, zero, zero, zero something', okay? That in experimental measurements is normal. That is close to what it has to be, even if it's not exactly. Because everything has its error. We were measuring with springs; besides, we were outside, we were not in the lab, that also makes you more distracted ... anyway.* (E#2; Y9.O2-Al)
	Direct instruction	***Al.- Is this affirmation true or false?: 'The deformations are equal to the deforming forces'.*** *S1.- False.* *Al.- OK, why is it false? What is deformation?* (E#3; Y9.O3-Al)
	Refers back to previous lessons	***Al.- When we talked about curves, some time ago, we said that the velocity is tangent to the trajectory. And it was you, one day that we were talking about that, who told me that if we were spinning in a carousel with swings, we would be shot off. Why?*** *Because if we were stopped being pulled towards the centre, then we would follow the velocity vector that we had at that moment. (...) It was you who said that, and I loved it, because it was not something that I proposed to you, the idea came out from you"* (E#12; Y11.O11-Al)
	Connects with an example	***Al.- Let's see the car example. We have the force of the motor which propels it forward; that's why it moves, isn't it?*** *And the wheels? Because the engine may propel it, but, cars, carts, all these things move with wheels, right? What is it that turns the wheels?* *S1.- The motor.* (E#4; Y9.O4-Al)
	Makes a claim	***Al.- Although we put a hand very close, very close to a pen, and we have a mass, and the pen has another mass, we are not able to attract it, right?*** ***S1.- That would be awesome.*** ***Al.- Yes, but that's not the case; why?*** *Because, even though it seems to us that the masses are very large and the forces are very large, it is really a weak force. That is why it occurs between very, very, very large masses.* (E#5; Y9.O5-Al)

Table A.8.4.c) Discourse moves present in Alba's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy* et al., 2016)*, and Kaartinen and Kumpulainen (2002).

ALBA'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Continuing moves	Checks understanding	*Al.- Yes. But it's farther. The strength depends on mass as well as distance. Then, it has more mass, the force is bigger. But it is further away, the force is smaller. Then, in that balance between mass and…, and distance, at that point it is in which it manages to rotate. if it were closer, maybe it would fall on the Sun. And if it were farther, maybe it would not turn around the Sun.* ***It is at the point where the force is in balance so that, with its speed, it can continue turning and neither escape nor fall, okay?*** (E#6; Y9.O6-Al)
	Completes students' questions	*S1.- If the Sun attracts the planets, and all that, and the Earth, the vector field ..., if you do so, the pen falls ... then,* ***why does the Sun not attract the Earth, like…?*** ***Al.- Why don't we crash into the Sun?*** *Because we have a speed. There is a speed. Remember when we saw the forces and saw the effects they could produce. One of them was the carousel with the swings. The carousel was spinning. And there was a force that pulled them towards the centre to always change their direction, right? Why doesn't that force make them crash into the central column of the carousel? Because they have a speed.* (E#7; Y9.O6-Al)
	Repeats (by rephrasing)	***Al.- When we have a stone tied to a rope and we make it spin, what happens to the stone when it is released?*** ***S1.- That it goes off.*** ***Al.- It follows out in a straight line towards [inaudible].*** *If we release it when it's high, it will continue horizontally. Why? Because the velocity is tangent to the trajectory, OK?* (E#13; Y11.O11-Al)
	Asks for examples	*Al.- OK, why is it false? What is deformation?* *S1.- When an object is deformed.* ***Al.- Now, give me an example. Give me an example in which, if you tell me it's false, they're different, right? Give me an example and tell me, define them...*** *S1.- A rubber band, when we stretch it, it will...* (E#3; Y9.O3-Al)
	Asks for confirmation	*Al.- Well, Ok, but when a car skids, when there is mud, when there is ice, the wheels slide, they do not spin. What does really make the wheels spin? It's the friction with the ground, okay? Then, the friction goes in the opposite direction. Because when the car moves towards that direction, the wheel does like this; then, the friction force is what pulls the wheel down, okay? There's almost no friction on ice ... Why do they use blades [referring to skaters]?* ***If there is no friction, they could skate with their feet, couldn't they?*** ***S2.- Yes.*** ***Al.- But they could not stop!*** *If there is no friction, how could they stop? They would land on their butts, and even so, they keep ..., right? So, they need blades, because when they want to brake or turn, and not to fall, eh…, they need to drive the blades into the ice to be able to stop, okay?* (E#4; Y9.O4-Al)

Table A.8.4.c) Discourse moves present in Alba's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy* et al., 2016), *and Kaartinen and Kumpulainen (2002).

<table>
<tr><th colspan="2">ALBA'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)</th><th>EXAMPLES</th></tr>
<tr><td rowspan="3">Continuing moves</td><td>Asks for justification</td><td>Al.- One question: how many significant figures does this result have to have?
S1.-One.
S2.- Two.
Al.- Why? Beth will explain why. Tell us, why two?
S2.- I know they must be two, but I do not know how to explain it. (E#15; Y9.O3-Al)</td></tr>
<tr><td>Asks for a definition</td><td>Al.- OK, and what's the deforming force?
S1.- The force you make to deform the rubber.
Al.- That's it, it's okay. In Hooke's law, the deforming force would be F; and the deformation, what would it be?
S2.- The elongation.
Al.- The elongation, that is. Very well! (E#3; Y9.O3-Al)</td></tr>
<tr><td>Asks for a different participant</td><td>Al.- One question: how many significant figures does this result have to have?
S1.-One.
S2.- Two.
Al.- Why? Beth will explain why. Tell us, why two?
S2.- I know they must be two, but I do not know how to explain it.
Al.- Do you need help from someone? Come, on, Anne.
S3.- Because if you get the data with two significant figures, the result also has to have two.
Al.- Ok, but the data ... we are given three data: 150, 35 and 45.
S3.- And two of them, that is, almost all, have two significant figures.
Al.- Mmm…, Athenea? (E#15; Y9.O3-Al)</td></tr>
<tr><td rowspan="2">Extending moves</td><td>Ignores an answer and changes direction</td><td>Al.- Let's see the car example. We have the force of the motor which propels it forward; that's why it moves, isn't it? And the wheels? Because the engine may propel it, but, cars, carts, all these things move with wheels, right? What is it that turns the wheels?
S1.- The motor.
Al.- Well, Ok. But when a car skids, when there is mud, when there is ice, the wheels slide, they do not spin. What does really make the wheels spin? It's the friction with the ground, okay? Then, the friction goes in the opposite direction.(E#4; Y9.O4-Al)</td></tr>
<tr><td>Rhetorical questioning</td><td>"When we talked about curves, some time ago, we said that the velocity is tangent to the trajectory. And it was you, one day that we were talking about that, who told me that if we were spinning in a carousel with swings, we would be shot off. Why? Because if we were stopped being pulled towards the centre, then we would follow the velocity vector that we had at that moment. (E#12; Y11.O11-Al)</td></tr>
</table>

Table A.8.4.c) Discourse moves present in Alba's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy **et al., 2016)*****, and Kaartinen and Kumpulainen (2002).***

ALBA'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		**EXAMPLES**
Referring moves (Makes explicit links to:)	Prior explications	*Al.- Why don't we crash into the Sun? Because we have a speed. There is a speed.* ***Remember when we saw the forces and saw the effects they could produce. One of them was the carousel with the swings.*** *The carousel was spinning. And there was a force that pulled them towards the centre to always change their direction, right? Why doesn't that force make them crash into the central column of the carousel? Because they have a speed.* (E#7; Y9.O6-Al)
	Prior knowledge	*Al.- The strength depends on the masses and the distance. And you are seeing that distance is also important. Because, in fact, it's true, the Sun is much bigger than the Earth. And it exerts a gravity on the Moon. But as the Moon is closer to the Earth, it is the action of Earth's gravity that prevails in that movement.* ***In fact, the tides… have you studied the tides yet?*** ***S3.- Yes, last year.*** ***Al.- Why are the tides produced?*** ***S4.- By the Moon.*** *Al.- By the Moon's gravity, right? But by the gravity of the Sun too. Do you know that there are spring tides and neap tides?* *Ss.- No.* *Al.- They are all tides, but we call 'spring' to those which are very strong. That is to say, there are many meters of difference between the low tide and the high tide, and the neap tides are those in which there are less differences. Why does that exist? Because when just the gravity of the Sun and the gravity of the Moon pull towards the same place, the tide is a spring tide. That is, the Sun's gravity acts on the body of water. The Moon has more influence for being closer, but the Sun too, because it is very big, okay?* (E#6; Y9.O6-Al)
	Practical aspects of scientific enterprise	*Al.- There's no n here, right?* [referring to the y-intercept] W*hy? Because more or less, it has to be zero. And almost everyone got that. You have obtained 'zero, comma, zero something, zero, zero, zero something', okay?* ***That in experimental measurements is normal. That is close to what it has to be, even if it's not exactly. Because everything has its error.*** *We were measuring with springs; besides, we were outside, we were not in the lab, that also makes you more distracted ... anyway.* (E#2; Y9.O2-Al)
	A future topic	*Al.- It follows out in a straight line towards [inaudible]. If we release it when it's high, it will continue horizontally. Why? Because the velocity is tangent to the trajectory, OK? So, how is it possible for bodies to turn? Because there is something that forces them all the time to change the address, okay?* ***In general, there is a force. Since the topic on forces is the next one in the syllabus, for now, we are going to say that there is an acceleration, okay?*** *Well, this acceleration, what it does, is to change the direction of the velocity vector all the time. And it always points to the centre.* ***It is called 'normal acceleration' or 'centripetal acceleration'. Centripetal because it points to the centre****.* (E#13; Y11.O11-Al)

Table A.8.4.c) Discourse moves present in Alba's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy* et al., 2016*), and Kaartinen and Kumpulainen (2002).

ALBA'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Replying moves	Responds to explicit questions	*S1.- Let's see, teacher. The Sun burns atoms to keep on burning. If it has already been billions of years burning, why doesn't it turn off?* *Al.- Because…, it's a bit complicated for you to understand, but basically because, although it's true that it's a big ball of He, H ...* ***S1.- Wouldn't they burn completely and that's all?*** ***Al.- No, because, they burn, well, they burn ..., it is that for you to burn is to being destroyed.*** ***(…)*** ***S1.- And when is it going to turn off?*** ***Al.- It's going to turn off, but I do not know if we know. Well, within millions of years.*** (E#8; Y9.O6-Al).
	Refuses to answer a question/go deeper	*S2.- And what if there are two suns?* *Al.- What if there are two suns? Oh, my God, I do not know! Well, if there were two suns, then maybe we would be 8, or ... I do not know.* ***I do not know, but if you are interested, you can continue studying on your own***. (E#6; Y9.O6-Al)
	Responds to a doubt with a question	***S1.- But I do not understand it; because, for example, Jupiter is much bigger than Earth, then, it should be closer to the Sun.*** ***Al.- Uh, no. Why?*** *S1.- Because… because it has more mass, then, it is more strongly attracted.* *Al.- Yes. But it's farther. The strength depends on mass as well as distance*. (E#6; Y9.O6-Al)
Commenting/reinforcing moves	Makes an encouraging remark	*S1.- Then, Pluto when it was a planet, how did it turn? Because if it's so far away, and it's small...* *Al.- Well, uh ... even if it's small, it's still very dense. That is, he has a lot of stuff in there.* ***I do not know the density of Pluto, but it is a very good question...*** (E#6; Y9.O6-Al)
	Adds some information and makes a reinforcing statement	*Al.- Although we put a hand very close, very close to a pen, and we have a mass, and the pen has another mass, we are not able to attract it, right?* *S1.- That would be awesome.* *Al.- Yes, but that's not the case; why? Because, even though it seems to us that the masses are very large and the forces are very large, it is really a weak force. That is why it occurs between very, very, very large masses.* ***Do you know what mass the Earth has?*** ***S2.- A lot.*** ***Al.- Of the order of 10 to 24 kg. A lot, indeed.*** (E#5; Y9.O5-Al)

Table A.8.4.c) Discourse moves present in Alba's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy* et al., 2016*), and Kaartinen and Kumpulainen (2002).

ALBA'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Concluding moves	Refers to a different area of knowledge	*Al.- They are all tides, but we call 'spring' to those which are very strong. That is to say, there are many meters of difference between the low tide and the high tide, and the neap tides are those in which there are less differences. Why does that exist? Because when just the gravity of the Sun and the gravity of the Moon pull towards the same place, the tide is a spring tide. That is, the Sun's gravity acts on the body of water. The Moon has more influence for being closer, but the Sun too, because it is very big, okay? OK, I'm interested in here that you have the idea, the concept of 'field', very clear. The field, which is the action that the masses suffer, in this case because it is a force between masses, around another that exercises that field. Since it is a field with arrows, that is, with vectors, it is called 'vector field'.* ***That is studied in mathematics at much higher levels. But you know that these vectors are studied mathematically, with numbers and so on.*** (E#6; Y9.O6-Al)
	Checks understanding and summarises	*Al.- Yes, but that's not the case; why? Because, even though it seems to us that the masses are very large, and the forces are very large, it is really a weak force. That is why it occurs between very, very, very large masses. Do you know what mass the Earth has?* *S2.- A lot.* *Al.- Of the order of 10 to 24 kg. A lot, indeed. If you divide it by three, it gives the order of 10 to 8 tons. Ten to 8 are 8 zeros. It is very large. I do not know the mass of the Sun. But they…, they are really very large masses. That is, it has to be something very, very, very massive, that is, to have a lot, a lot of mass, to be able to attract something else. Although we believe that we are very fat and we are very heavy, we are unable to attract a speck of dust, okay? Even if it's close.* ***Understood? It is a weak force.*** (E#5; Y9.O5-Al)
	Provides a conclusive answer	*S1.- Let's see, miss. The Sun burns atoms to keep on burning. If it has already been billions of years burning, why doesn't it turn off?* *Al.- Because…, it's a bit complicated for you to understand, but basically because, although it's true that it's a big ball of He, H…* *S1.- Wouldn't they burn completely and that's all?* *Al.- No, because, they burn, well, they burn ..., it is that for you to burn is to being destroyed. (…)* ***S1.- And when is it going to turn off?*** ***Al.- It's going to turn off, but I do not know if we know. Well, within millions of years***. (E#8; Y9.O6-Al).

Table A.8.4.c) Discourse moves present in Alba's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy* et al., 2016*), and Kaartinen and Kumpulainen (2002).

ALBA'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Concluding moves	Repeats and makes a confirming comment	*Al.- OK, and what's the deforming force?* *S1.- The force you make to deform the rubber.* *Al.- That's it, it's okay. In Hooke's law, the deforming force would be F; and the deformation,* ***what would it be?*** ***S2.- The elongation.*** ***Al.- The elongation, that is. Very well!*** (E#3; Y9.O3-Al)
	Refers to sociological dimensions of scientific enterprise	*S1.- But inside a black hole, time does not pass, nor anything, right?* *Al.- Yes, sure! It captures everything.* ***I'm sorry to tell you that your physics and chemistry teacher does not know everything. Partly because of my ignorance and partly, because we do not know everything. That is why there is the R + D + I, to continue researching***. (E#9; Y9.O6-Al)
	Gets back to the main topic	*Al.- They are all tides, but we call 'spring' to those which are very strong. That is to say, there are many meters of difference between the low tide and the high tide, and the neap tides are those in which there are less differences. Why does that exist? Because when just the gravity of the Sun and the gravity of the Moon pull towards the same place, the tide is a spring tide. That is, the Sun's gravity acts on the body of water.* ***The Moon has more influence for being closer, but the Sun too, because it is very big, okay? OK, I'm interested in here that you have the idea, the concept of field, very clear*** (E#6; Y9.O6-Al)
	Introduces a new a term	*Al.- It follows out in a straight line towards [inaudible]. If we release it when it's high, it will continue horizontally. Why? Because the velocity is tangent to the trajectory, OK? So, how is it possible for bodies to turn? Because there is something that forces them all the time to change the address, okay? In general, there is a force. Since the topic on forces is the next one in the syllabus, for now, we are going to say that there is an acceleration, okay? Well, this acceleration, what it does, is to change the direction of the velocity vector all the time. And it always points to the centre.* ***It is called 'normal acceleration' or 'centripetal acceleration'. Centripetal because it points to the centre***. (E#13; Y11.O11-Al)
	Refuses to answer a question	*S1.- But inside a black hole, time does not pass, nor anything, right?* *Al.- Yes, sure! It captures everything. I'm sorry to tell you that your physics and chemistry teacher does not know everything. Partly because of my ignorance and partly, because we do not know everything. That is why there is the R + D + I, to continue researching.* ***Ok, another question. Is it about black holes or about springs?*** ***S2.- Black holes.*** ***Al.- Then, no***. (E#9; Y9.O6-Al)

With regard to the patterns of interaction observed in Alba's episodes (Table A.8.4.d), there are four different kinds of sequences: i) a student asks a question, and Alba replies without involving the students; ii) Alba poses a why-question and does practically all the reasoning; iii) IRF sequences, where Alba initiates the dialogue with a question which is answered by a student, who receives explicit feedback (E#3-A); and 4) Alba and the students engage in a dialogue in which they continually interrupt each other to raise doubts, introduce clarifications, rephrase a question or emphasise something. This type of exchange can only occur in environments where students feel confident, something Alba says to be proud.

PATTERNS OF INTERACTION	EXAMPLES
Student's question – Teacher's answer	***S1.-*** *Why does it have a minus sign? [referring to the law Alba has written on the whiteboard: F=-k·Δx]* ***Al.-*** *The other day, when we reviewed Hooke's Law and saw Newton's law, I told you that, in Hooke's law, this force is exerted by the spring. But here, we are not measuring what [force] the spring exerts, we are measuring what [force] we apply. The spring exerts a force against. As it goes against stretch, it has a minus.* (E#1; Y9.O2-Al)
Teacher's question – teacher's answer	***Al.-*** *There's no n here, right?* [referring to the y-intercept] W*hy? Because more or less, it has to be zero. And almost everyone got that. You have obtained 'zero, comma, zero something, zero, zero, zero something', okay? That in experimental measurements is normal. That is close to what it has to be, even if it's not exactly. Because everything has its error. We were measuring with springs; besides, we were outside, we were not in the lab, that also makes you more distracted ... anyway.* (E#2; Y9.O2-Al)
Alternation with interruptions	*S1.- Let's see, teacher. The Sun burns atoms to keep on burning. If it has already been billions of years burning, why doesn't it turn off?* ***Al.- Because…, it's a bit complicated for you to understand, but basically because, although it's true that it's a big ball of He, H ...*** ***S1.- Wouldn't they burn completely and that's all?*** *Al.- No, because, they burn…, well, they burn ..., it is that for you to burn is to being destroyed...* *S1.- To combust.* *Al.- Not here. Here to burn is to get separated, or lose electrons, or ..., then, when they move away and cool down, then they recombine again; and then, due to gravity, they return ... it's like a circle.* *S1.- And when is it going to turn off?* *Al.- It's going to turn off, but I do not know if we know. Well, within millions of years. (E#8; Y9.O6-Al).*
IRF sequence	*Al.- Is this affirmation true or false?: 'The deformations are equal to the deforming forces'.* *S1.-* ***False.*** ***Al.- OK, why is it false? What is deformation?*** *S1.- When an object is deformed.* *Al.- Now, give me an example. Give me an example in which, if you tell me it's false, they're different, right? Give me an example and tell me, define them...* *S1.- A rubber band, when we stretch it, it will...* *Al.-* ***OK, and what's the deforming force?*** ***S1.- The force you make to deform the rubber.*** ***Al.- That's it, it's okay. In Hooke's law, the deforming force would be F; and the deformation, what would it be?*** ***S2.- The elongation.*** ***Al.- The elongation, that is. Very well!*** (E#3; Y9.O3-Al)

Table A.8.4.d) Patterns of interaction present in Alba's episodes on explanation

A.8.5. Alba's Knowledge of Assessment (KAs)

My first thought after transcribing Alba's 15 episodes was that there was nothing to report about her Knowledge of Assessment of scientific explanation. I found no evidence that Alba possessed any structured view, model, or tool designed to assess students´ ability to produce scientific explanations. Alba does not propose or plan activities whose goal is to engage students in building an explanation to a given phenomenon, neither individually nor collectively. Nor does she ever ask students to develop written explanations. Therefore, it seemed coherent that Alba did not assess this practice.

In the interview, Alba acknowledged that, for her, the most important dimension to assess was students' progress, both about their knowledge and thinking-skills acquisition. The ability to engage in explanation building could fall into the second category. Alba also affirmed that she lacks the tools to accomplish this type of assessment, so that in the end, she opts for standard tests. In Alba's tests, reasoning questions are not included for purely pragmatic reasons. Following the Science Department indications, Alba's summative assessment also includes homework, lab-reports and students' class performance; but in none of these elements does Alba include activities for the elaboration of scientific explanations (although in some lab-reports students are asked to *explain* how they have conducted an experiment). In her interview, Alba mentioned that students, especially the oldest ones, only show interest in a task if this is assessed and has some influence in their final grade. Since Alba never assesses the explanations given by the students, they could perceive this as a non-relevant practice.

In the episodes of oral construction of explanations, we do find some methods for informal assessment that Alba implements to gauge students' comprehension during the process, such as questioning. This strategy may provide her with a general sense of what the students understood about some conceptual aspects, but not a deep comprehension of specific students' ideas and areas of difficulty for explaining things. In some cases, when Alba questions the students, she is satisfied with a one or two-word answer, to which she usually adds her own explanation rather quickly (E#4-Al). On other occasions, Alba chains a series of questions, until some student figures out the right answer. In these cases, students are given more time to think (E#3-Al). These slightly different behaviours might correspond to Alba's oscillating orientation toward science teaching, which is reflected in the aforementioned tension between desire and act. On the one hand, Alba usually thinks there is one answer to her questions and one way to solve problems. It is her responsibility, she opines, to show students how to do something and for students to practice until they get it. But on the other hand, Alba also believes that students should have some responsibility in the learning process, and so, they should do some of the reasoning.

A.8.6. Alba's PCK of Scientific Explanation. Summary and discussion

Alba's lessons are quite traditional in many aspects. They are focused on delivering content that students must assimilate and on reiterating algorithmic standard problems to develop students' mathematical skills. Under this drill-and-skill approach, none of the activities Alba proposed seemed to have been designed to cognitively provoke the students. Moreover, although Alba involved students with continuous questions, these had usually a closed character. Something similar happened with the assessment methods; despite including laboratory-work and students' contributions, Alba's assessment system was test-based in a high percentage.

When talking with her, I soon realised that Alba's goals and aspirations do not match this panorama. Alba would like to work on projects, give the students time to ask many questions, think for themselves, experience science. As she admitted on some occasions throughout the interview, Alba struggles to reconcile the constructivist, student-centred, view on teaching in which she believes, with the didactic, teacher-centred, view in which she was encultured as a student and that she ends up recreating.

As early as 1968, Johnson and Seagull (1968) already called attention to this dichotomy between actions and words. According to these authors, teachers are too often educated through a lectured-based way of teaching; and despite having also been exposed to alternative conceptual frameworks about learning and teaching, novice teachers tend to perpetuate didactic and lecture-based methods in their classrooms. With this, the students' role is relegated to "[l]isten and take notes; learn by watching; depend on authorities; [and] give [teacher] what [s]he wants" (Johnson and Seagull, 1968, p. 167). Although a lot of water has flowed under the bridge since then, many researchers continue to note there is a mismatch between teachers' beliefs about learning and teaching, and their practice (Schulz, 2014). With respect to non-experienced teachers, numerous studies indicate that, even after receiving education about other instructional approaches, they either not know how to enact these ideas once in the classroom, or simply reject these frames and rely instead on conservative teacher-centred instruction (Abd-El-Khalick *et al.,* 1998; Brickhouse & Bodner, 1992; Windschitl & Thompson, 2006).

Some authors suggest that the reasons for this mismatch may be found in novice teachers' excessive attention to subject-matter content and other aspects, such as classroom management (Barreto-Espino, 2010). Alba enumerates some constraining elements for the implementation of instructional approaches conducive to more meaningful and active students' participation. In addition to her acknowledged lack of training and experience, Alba alludes to the extension and contents of the curricula and the high number of students per classroom. In this, she coincides with Nargund-Joshi and colleagues (2011). These researchers reported the difficulties that two science teachers with a reform-based orientation towards science experienced in enacting their beliefs into classroom practice, due to contextual constraints; these included large classes, limited time, and emphasis on external examination. This eventually resulted in an undermining in their determination of bringing their ideas and perspectives into practice, so that their classes ended up shifting towards didactic approaches. I think it is important to keep these external constraints in mind, as they can also have an appreciable impact on the learning objectives set, the type of instructional strategies used, and the kind of environments that teachers can create. This is something that many authors who aim to reveal the connections between different PCK elements do not consider, so their analysis may be somewhat incomplete. This is, for example, the case of Park and Chen (2012), who found that the didactic orientation towards science (OTS) hold by science teachers influenced their knowledge of instructional strategies (KIS) in such a way that it inhibited connections with other PCK components. In this study, it would have been interesting that they had considered the degree of influence that external factors, such as those mentioned, may have on the connections between different PCK components.

Alba's OTS and teaching practice coincides to a large extent with the predominant perspective in secondary education in Spain during the last decades (Garcia, 2008). Therefore, I was not too surprised for not having witnessed any authentic episode of scientific explanation production in her lessons. However, in her interview, Alba portrayed science as a way of being in the world, and on several occasions, she mentioned a scientific way of thinking. Moreover, she claims that the constant search for explanations is what characterises the day-to-day of scientists. Considering all this, it is at least curious that Alba does not try to create opportunities for students to experience this way of being, thinking, and acting. Alba's orientation towards teaching might give us some clues to understand this absence, but we should look for some other reasons.

Explicating science content is familiar territory for Alba; she admits feeling at ease with this teaching method. This might be one of the reasons for the overwhelming dominance of Alba's talk in the classroom discourse. Given the mastery she displays in this teaching practice, it is not surprising that thanks to it Alba achieves many of her intended learning objectives. The problem is that the type of environments supported by this teaching approach does not seem to be the most conducive to generating opportunities for students' engagement in authentic epistemic practices. Sandoval and Reiser (2004) define epistemic practices as "the reasoning and discursive practices involved in making and evaluating (…) scientific knowledge" (p. 368). The role language plays in these practices makes them "interactional"; that is, they must be "constructed among people through concerted activity" (Kelly & Licona, 2018, p. 140). Berland *et al*. (2016) supplement this affirmation by claiming that the development of epistemic activities requires a dialectic interaction between individuals with different backgrounds and the classroom community as a whole. Then, for students to have opportunities to create their scientific explanations, Alba should promote discourse dynamics with space for co-construction. And this requires having a certain level of competence and expertise to coordinate and moderate students' interventions, to scaffold and guide the process, and to explicitly reflect about the knowledge, reasoning elements and criteria they use for producing their explanation (Driver *et al.,* 2000). Sandoval (2005) suggests that students need to attend explicitly to the discourse that takes place during the construction of a scientific explanation; otherwise, they would not develop an informed understanding of what 'doing science' involves.

A.8.7. Explanation-building episodes in Alba's lessons.

EPISODE 1 (E#1; Y9.O2-Al).

S1.- ***Why does it have a sign 'minus'?*** [FN_EIA: referring to the law Alba's has written on the whiteboard: F=-kΔx].

Al.- The other day, when we reviewed Hooke's Law and saw Newton's law, I told you that, in Hooke's law, this force is exerted by the spring. But here, we are not measuring what [force] the spring exerts, we are measuring what (force) we apply. The spring exerts a force against. As it goes against stretch, it has a minus.

EPISODE 2 (E#2; Y9.O2-Al).

*Al.- There's no 'n' [*FN: y-intercept] *here, right?* ***Why?*** *Because more or less, it has to be zero. And almost everyone got that. It gives you 'zero, comma, zero something, zero, zero, zero something', okay? That in experimental measurements is normal. That comes close to what it has to be, even if it's not exactly that. Because everything has its error. We were measuring with springs; besides, we were outside, we were not in the lab, that also makes you more distracted ... anyway.*

EPISODE 3 (E#3; Y9.O3-Al).

Al.- Is this affirmation true or false: 'The deformations are equal to the deforming forces'?.

S1.- False.

Al.- OK, ***why is it false?*** *What is deformation?*

S1.- When an object is deformed.

Al.- Now, give me an example. Give me an example in which… If you tell me it's false, they're different, right? Give me an example and tell me, define them ...

S1.- A rubber band, when we stretch it, it will ...

Al.- OK, and is the deforming force?

S1.- The force you make to deform the rubber.

Al.- That's it, it's okay. In Hooke's law, the deforming force would be F; and the deformation, what would it be?

S2.- The elongation.

Al.- The elongation, that is. Very well!

EPISODE 4 (E#4; Y9.O4-Al).

Al.- Let's see the car example. We have the force of the engine that propels it forward; that's the reason why it moves, isn't it? What about the wheels? Because the engine can propel it but cars, carts, all these things, move with wheels, right? What makes the wheels spin?

S1.- The engine.

Al.- Well, ok, but when a car skids, when there is mud, when there is ice, the wheels slide, they don't spin. What does really makes the wheels spin? It's the friction with the ground, okay? Then, the friction goes in the opposite direction. Because when the car moves towards that direction, the wheels do like this; then, the frictional force is what pulls the wheel down, okay? There is almost no friction on ice ... ***Why do they*** **[FN: Ice skaters]** ***use blades?*** *If there is no friction, they could skate with their feet, right?*

Ss.- Yes.

Al.- But they could not stop! If there is no friction, how could they stop? They would land on their butts, and even so, they keep… don't they? So, they need blades, because when they want to brake or turn, and not fall, uh, they need to stick the blades in the ice to be able to stop, okay?

EPISODE 5 (E#5; Y9.O5-Al).

Al.- Although we put a hand very close, very close to a pen, and we are a mass, and the pen has another mass, we are not able to attract it, right?

S1.- That would awesome.

Al.- Yes, but ***that's not the case; why?*** *Because, even though it seems to us that the masses are very large, and the forces are very large, it is really a weak force. That is why it occurs between very, very, very large masses. Do you know what mass the Earth has?*

S1.- A lot.

Al.- About 10 to the power of 24 kg. A lot. If you divide it by three, it gives you 10 to [the power of] 8 tons. Ten to 8 is ten, followed by 8 zeros. It is huge! I do not know the mass of the Sun. But… they have really, very, large masses. That is, it has to be something very, very, very massive, that is, to have a lot, a lot of mass, to be able to attract something else. Although we believe that we are very fat and we are very heavy, we are unable to attract a speck of dust, okay? even if it's close, understood? It is a weak force.

EPISODE 6 (E#6; Y9.O6-Al).

S1.- But, miss, what about, for example, the Earth and Uranus ...? The Earth compared to Uranus.

Al.- Uranus is bigger, isn't it?

S1.- Sure.

Al.- Then, it has a greater gravitational field.

S1.- So, ***is it that the reason why it is farther?***

Al.- No, Gosh! [It's] because ... no, but, uh ..., it means that ..., to see, eh ..., the attractive force is smaller and that's why it [Uranus] is farther away. And what does happen is that the orbit is larger, it [Uranus] is at a greater distance. But it [the Sun] has the capacity to attract it [Uranus], because its mass is larger than ours. Under the same circumstances, the Earth at that distance, since it is smaller, would not turn around the Sun; maybe, right? That is, it depends on the masses and depends on the distances. Can larger planets be attracted farther? Yes, because the force is bigger. That is, there is a reason behind, of course. In the same way, the Earth, with its actual size and the mass that it has, could not be in Uranus' place. I do not know, Ok? I have not made the calculations, but it can be calculated and maybe it escapes because it [the Earth] does not have enough mass to be attracted by the Sun.

S2.- But I do not understand it. Because, for example, Jupiter is much bigger than the Earth, then it should be closer to the Sun.

Al.- Uh, no, ***why?***

S2.- Because… Because it has more mass, it is more strongly attracted.

Al.-. Yes. But it's farther. The force depends on mass as well as distance. Then, the more the mass, the stronger the force. But since it is farther away, the force is smaller. Then, in that balance between mass and…, and distance, at that point is in which it manages to turn around. If it were closer, maybe it would fall on the Sun. And if it were farther, maybe it would not turn around the Sun. It is at the point where the force is in balance so that, with its current speed, can continue turning and neither escape nor fall, okay?

S1.- Then, Pluto, when it was a planet, how could it turn around [the Sun]? Because if it's so far away, and it's small ...

Al.- Well, uh ... even if it's small, it's still very dense. That is, he has a lot of stuff in there. I do not know the density of Pluto, but it is a very good question ... if it turns it is because there is a force that is in balance. That is to say, with the speed at which it goes and the force that exists, it is attracted by the Sun, so it must be dense, have enough mass to be attracted by the Sun. Otherwise, it would escape. It would not turn around. With its current speed, it just keeps moving.

S3.- What if there were two suns?

Al.- What if there were two suns? Oh, my Gosh, I do not know! Well, if there were two Suns, then maybe we would be 8, or ... I do not know. I do not know, but if you are interested, you can continue studying on your own. Next question.

S4.- Miss, then, if the Sun attracts the Earth so strongly, ***why does the Moon revolve around the Earth and not the Sun?***

Al.- Because it is closer.

S4.- Ok, miss, I know, but…

Al.- The force depends on the masses and the distance. And you are seeing that distance is also important. Because, in fact, it's true, the Sun is much bigger than the Earth. And it exerts a gravitational [force] on the Moon. But as the Moon is closer to Earth, it is the action of Earth's gravity that prevails in that movement. In fact, the tides…Have you studied the tides yet?

Ss.- Yes last year.

Al.- Why are the tides produced?

S5.-By the Moon.

Al.- By the gravity of the Moon, right? But by the gravity of the Sun too. Do you know that there are live tides and dead tides?

Ss.- No.

Al.- They are all tides, but we call 'live' those which are very strong; that is to say, there are many meters of difference between the low tide and the high tide. And the dead tides are in which there are less differences. Why does that exist? Because when the gravity of the Sun and the gravity of the Moon pull towards the same place, the tide is a living tide. That is, the Sun's gravity acts on the body of water. The Moon has more influence because it's closer, but the Sun too, because it is huge, okay? OK, I'm interested in here that you have the idea, the concept of field, very clear. The field, which is the action that the masses experiences (in this case, because there is a force between masses) in the proximities of another [mass] that produces that field. Since it is a field with arrows, that is, with vectors, it is called 'vector field'. This is studied in mathematics at much higher levels. But you know that these vectors are studied mathematically, with numbers and so on.

EPISODE 7 (E#7; Y9.O6-Al).

S1.- If the Sun attracts the planets, and all that, and the Earth, the vector field ..., if you do so, the pen falls ... then, ***why does the Sun not attract the Earth****, like…?*

Al.- ***Why don't we crash into the Sun?*** *Because we have a speed. There is a speed. Remember when we saw the forces and saw the effects they could produce. One of them was the carousel with the swings. The carousel was spinning. And there was a force that pulled them towards the centre to always change their direction, right? Why doesn't that force make them crash into the central column of the carousel? Because they have a speed. If suddenly, that stops, of course, everyone would crash with each other. But as long as you have a speed, that force is not able to take you towards the centre. It changes the direction and that's why you turn, but you cannot change… cannot decrease that distance, okay?*

EPISODE 8 (E#8; Y9.O6-Al).

S1.- Let's see, Miss. The Sun burns atoms to keep burning. If it has already been billions of years burning, ***why doesn't it turn off?***

Al.- Because…, it's a bit complicated for you to understand, but basically because, although it's true that it's a big ball of He, H ...

S1.- Wouldn't they burn completely, and that's all?

Al.- No, because, they burn, well, they burn ..., it is that, for you, to burn is to be destroyed.

S1.- To combust.

Al.- Not there. There, to burn is to separate, or lose electrons, or ..., then, they move away and cool down, because they recombine again, and then, by gravity they return ... it's like a circle.

S1.- And when is it going to turn off?

Al.- It's going to turn off, but I do not know if we know. Well, within millions of years.

EPISODE 9 (E#9; Y9.O6-Al).

S1.- Miss, what about a black hole? ***Why does it attract us?*** *Do they have gravity or what?*

Al.- Oh, my Goodness! Black holes have huge, huge, huge mass. Then, they attract everything that is around them. What's going on in there? We do not know ... I do not know if anyone has gone, but certainly no one can return. Because it is like a place where the whole mass enters, it attracts the whole mass. It has a lot of mass very, very concentrated.

S1.- But inside a black hole, time does not pass, nor anything, right?

Al.- Yes, sure! It captures everything. I'm sorry to tell you that your physics and chemistry teacher does not know everything. Partly, because of my ignorance. And partly, because we do not know everything. That is why there is R+D+I, to continue researching. Ok, another question. Is it about black holes or about springs?

S2.- Black holes.

Al.- Then, no.

EPISODE 10 (E#10; Y11.O1-Al).

Al.- I have a question for you. Does this line that you have put here have a positive or a negative slope?

Ss.- Positive.

Al.- The equation, positive; but the line that we have drawn, can you see that it goes down? The slope has to be negative. Can everyone see that? Well; then, ***you put a minus here at the front. Why?*** *Because it goes against what we have marked in the position. The position grows up, right? And this goes down.*

S1.- But is it just to get it right, or ...?

Al.- Yes, sure. That 'minus' does not mean that ... let's see, it only makes physical sense.

EPISODE 11 (E#11; Y11.O4-Al).

[FN_EIA: Some try to explain why the doors fail]

S1.- Maybe it's the metal that does not detect it.

[FN_EIA: They look for causes spontaneously; she does not ask them that].

EPISODE 12 (E#12; Y11.O11-Al).

Al.– When we talked about curves, some time ago, we said that the velocity is tangent to the trajectory. And it was you, one day that we were talking about that, who told me that ***if we were spinning in a carousel with swings, we would be shot off. Why?*** *Because if we were stopped being pulled towards the centre, then we would follow the velocity vector that we had at that moment. (...). It was you who said that, and I loved it, because it is not something that I proposed to you, the idea came out of you.*

EPISODE 13 (E#13; Y11.11-Al).

Al.- When we have a stone tied to a rope and we spin, what happens to the stone when it is released?

S1.- That it goes off.

Al.- It follows out in a straight line towards [inaudible]. ***If we release it when it's high, it will continue horizontally. Why?*** *Because the velocity is tangent to the trajectory, Ok? So, how is it possible for bodies to turn? Because there is something that forces them all the time to change the direction, okay? In general, there is a force.*

EPISODE 14 (E#14; Y9.O5-Al).

Al.- There are two zones on the same magnet. And what happens if we cut the magnet? Does it exist a North pole alone and a South pole alone?

Ss.- No.

Al.- No

*S1.- **Why not?***

Al.- Because that's what experience says. if I break this magnet in two pieces, one of the pieces is going to attract the other one, the other part is going to repel it. There are always the two poles in the magnet.

EPISODE 15 (E#15; Y9.O3-Al).

Al.- One question: how many significant figures does this result have to have?

S1.- One.

S2.- Two.

*Al.- **Why? Alice will explain why. Tell us, why two?***

S2.- I know they must be two, but I do not know how to explain it.

A.- Do you need help form someone? Come on, Anne.

S3.- Because if you get the data with two significant figures, the result also need to have two.

Al.- Ok, but the data… we are given three data: 150, 35 and 45.

S3.- And two of them, that is, almost all, have two significant figures.

Al.- Mmm…, Athenea?

S4.- Because from the data you are given, the one with less significant figures has only two. If you put three, you are guessing one.

Al.- That is! There are three data. Two of them have two, and the other, three. It is not just the majority. It's because the minor number of significant figures in the data is two.

A.9. BARNEY'S CASE

BARNEY	YEAR 8	YEAR 10	YEAR 11
CLASSES	3 hours/week	2 hours/week	3 hours/week
No. OF GROUPS	1	1	1
No. STUDENTS/GROUP	29	25	27
No. OBSERVED LESSONS	8	7	7
TOPICS	Plagues; Research work about plants; Plants experiment	The hormonal system; Healthy life (cardiovascular diseases, life expectancy)	Genetics
EXPLANATORY EPISODES	6	4	6

Table A.9) Details about Barney's observed lessons.

A.9.1. Description of classroom context and teaching

Barney is a 13-years' experience teacher who speaks passionately about Biology and about teaching. Despite his current love for teaching, Barney was not always clear he wanted to devote to this profession. He did a Degree in Biology because he wanted to learn "*as much as possible about animals".* His first job as a biologist was in the Doñana National Park. He spent three years researching rabbits' behaviour. Although he found this job "*fascinating*", he was not entirely satisfied because he "*had to work almost alone*" (I-Ba). So, when his contract expired, he decided to prepare for the Spanish national examination to become a teacher. On the same day that Barney was told he had failed, he was called from School-B for an interview for Science teacher. He succeeded, and since then, he has been working in the same place[7].

Barney confesses being "*completely in love*" with his school. He values the diversity of the people who work there –"*who are humble to learn and confident to teach*", their passion for education and their closeness with the students –"*something missing in other educational centres because of the number of students*" (I-Ba). Barney considers perfect the size of the school so that they can deeply involve the families (§4.4). This involvement is achieved thanks to fluid communications with them, being open to constructive criticism, and generating a climate of trust and respect. This derives, in turn, from the fact that all teachers have "*a common view that focuses on the development of the humanity of (the) students*". The strong degree of coherence and cohesion among the teaching staff (in "*educational values*" and "*pedagogical perspectives*") facilitates teamwork, as well as the work of each teacher individually. Barney says he is very grateful for the support the management team lavishes on him, and the other teachers. They feel they can propose new activities and methodologies. In Barney's case, this support has been crucial to improving as a professional.

His lack of confidence in subject matter knowledge –"*I consider myself more passionate than cultured*"– is something Barney tries to ameliorate. He reckons this might be due to his "*poor and messy memory*", which makes it hard for him to retain scientific data and concepts – "*a small drama for a science teacher*" (I-Ba). Barney must prepare his classes well in advance, and to be constantly searching for new information. Fortunately, he says, he is curious and passionate about his subject, so he does not find it tedious to have to acquire new knowledge – "*Science is advancing and I would like to learn all about it; I mean, all the current stuff, not only the things that I studied [in my degree]. And as soon as I learn something, I try to share it with my students*" (I-Ba). To this, he adds he loves teaching so much that he really enjoys investigating and implementing new teaching strategies, new types of activities, and new materials and resources, so that every day he feels "[*he is*] *learning while teaching others*" (I-Ba). Barney does not hesitate to openly show his students that he is an apprentice more who does not have all the answers, in an attempt to reinforce his belief that learning is a lifelong process –"*I have taken*

[7] Barney gave explicit consent to the publication of this level of personal information for academic purposes, after having been informed that this might enable his identification.

the time to do my own infographic, which I had never done before either. So, I learn as the same time as you!" (Y10.O1-Ba).

In Barney's case, it is very difficult to establish a line to separate his role as a teacher and his personality beyond the classroom; this is something he corroborates with the affirmation that "*for me, to be a teacher is to unleash the person that I am*" (I-Ba). He does not talk about the students, but about *his children*, whom he wants to "*always accompany and to arouse their interests, rather than teach them"*. Barney recognises that something that characterises him as a person (and as a teacher, by extension), is that he sees all the children as "*interesting and loving people*", and that, just as he does with adults, he "*focus[es] on their positive things, on their virtues, regardless of their age"*, in order to "*learn something back from them*" (I-Ba). Barney seems to be genuinely interested in every one of his students as individuals. In his lessons, this means that students have a voice within the group. Their ideas, their passions, their concerns, and even their fears are shared and appreciated by all. In order to get the students to participate in this climate, Barney shows trust on them and also shares very personal aspects of his life, but these are always clearly framed within the objectives of the lesson. For example, to introduce the topic of healthy habits in Year 10, Barney proposed an activity that caught the attention of the students, who took it very seriously.

> *"As you know, I personally like being alive. I'm going to try very hard to keep alive as much as I can, but if there's one thing that makes us all the same, it's death. In the end, we will all die. And today we are going to talk a little about that. So, I'm going to ask you to do a very simple opening activity. Please, close your eyes and think of a dream of yours that is real, possible, attainable. Do not think 'I want to fly', but something achievable. A future dream that you had raised for your life. There are people who will have it very clear, and people who have never thought about it. I'll give you a minute to think about an individual dream that you have". (*Y10.O2-Ba*)*

Originality and diversity when it comes to devising activities are characteristics that Barney considers making him a good teacher. Convinced that children get bored if all classes are the same, he puts his scientific knowledge, his pedagogical knowledge, his intuitions, and his creativity at the service of students' learning. In addition to being creative, Barney self-defines as a calm, patient, and discreet person, a little disorganised but with a great sense of humour. These are the necessary conditions –so he thinks– to create a climate of trust and respect that suppose the ideal breeding ground for meaningful learning. In Barney's opinion, once the ground has been prepared, the next step is to be clear about the learning objectives. Having well-defined objectives is not only useful for him when designing the course, planning the lessons or deciding what learning dimensions are worth to assess; understanding the rationale behind the activities in which they engage may help the students to organise their thoughts and ideas. That is why, in many lessons, Barney explicitly states these objectives.

In our interview, Barney claimed his main mission as a teacher is "*to awaken each student's particular interest*". This is also one starting point he considers when it comes to designing and planning lessons. The mandatory National Curriculum is the other point. Parents, education inspectors, and even the students exert some pressure for the curriculum to be followed as thoroughly as possible. Barney says this causes him some concern because there are aspects of the curriculum that he finds unimportant for his students' personal and scientific development. The biggest challenge for Barney is, then, to achieve a balance between the demanded target –covering the curriculum– and his personal target –maintaining students' motivation towards his subject. To get this balance, Barney selects and/or adapts those topics that are closest to students' reality and necessities –"*Eventually*, *every teacher makes concessions because they lack time; then, instead of starting with the first topic and see how far I can get, I prefer to select based on the criterion of usefulness for them*" (Ii-Ba).

Barney's objectives and the strategies he uses to promote them are strongly influenced by how he conceptualises and understands the teaching-learning process. Barney defends the position that for meaningful learning to occur, the student must be emotionally engaged in the process of knowledge construction –"*The children take care of their plants with great affection, which makes them want to learn more about plants in general*" (Ii-Ba). This emotional engagement must be accompanied by active involvement. That is, Barney firmly believes that the classroom must offer opportunities to actively participate in different practices, since this might provide students with a type of knowledge, attitudes and values that cannot be acquired by mere transmission –*I value much more those active, creative, and participatory aspects which occur in our little garden, than those occurring inside the classroom, with the student sitting quietly at the table and being exposed to theoretical questions". (I-Ba)*

Teachers in School-B are encouraged to introduce a cooperative-learning approach in their classes. This perspective fits perfectly with Barney's conceptualisation of education and objectives since, for him, the school should be the place where students develop "*not only as individuals but also as members of a community or society*". And, given that the society where his students live is global, they will have to "*face teamwork tasks (…) and they will have to help* *each other to achieve common goals*" (I-Ba). Then, cooperative learning is an essential approach for him. In all the Year 10 and Year 11 sessions I attended, the students engaged in small-groups and/or whole-class activities, in which they had to contribute in different manners to the final product.

In Year 8, Barney's approach was different, since one of his mains goals in this educational level is to promote students' autonomy. This was patent both in their classroom activities and in the vegetable garden – *"My proposal is for you to face this activity alone. I want everyone to design their own way of marking (the plants). So, do not start asking me things, because I'm not going to tell you how you have to do it.* (Y8.O1-Ba).

To acquire some autonomy in the knowledge-construction process is one of Barney's goals for all his students. To achieve this, it is necessary to trust them. And he can trust them because he knows them personally and in-depth, he says. Moreover, within the group class, the perspective of each individual is heard, respected and valued–"*(f)or me, your criterion may be as valid, or even better, than that of many adults"* (Y10.O5-Ba). This encourages, in turn, that genuine peer and student-teacher dialogic interactions (Hennessy *et al.*, 2016) can take place in the classroom, giving the students opportunities for exploring on ideas, comparing ideas, differentiating between ideas, and developing ideas. That is, Barney's students are immersed in a dialogic rather than hierarchical pedagogical environment (Garcia-Mila & Andersen, 2007). Barney believes that, in this environment, students can learn things that go beyond content knowledge, which are also essential to develop as individuals and citizens. For example, during my last week in School-B, Barney and I prepared a couple of lessons about argumentation for the Year 10 students. To introduce the activity that we had planned (on the origins of humans' ethical behaviour), Barney stressed: "*The goal is to open the mind and listen to others. I expect that makes us reflect about the issue we have been working. Note that this can be extrapolated to other topics of your life, okay?*" (W-Ba).

Barney is convinced that reflection-pursuing activities may have a positive impact on students' relationships with their learning. Therefore, he designs numerous activities to foster students' reflective capacity –*"(w)e will analyse your answers, and, through them, we'll reflect. This class is for reflection"* (Y10.O3-Ba). He also asks the students to reflect on and evaluate their work –"*If you had to criticise your Prezi®, what would you say?* (Y9.O6-Ba). Similarly, whenever he can, Barney requests the students to assess their classmates' work, because this may help them compare with their own performance and see what they have done well and how they could improve.

He uses the same strategy with exam results. Thus, when someone fails in an exam, Barney tries to make them think about it not as a defeat, but as an opportunity for improvement. Together with the student, he analyses the possible causes for the failing grade and tries to propose solutions. Barney is especially interested in students being able to reflect on these solutions and, if possible, that they propose their own.

Barney uses an original and variated assortment of assessment tools. He considers that education, as individuals, is multifaceted; as there are so many dimensions to assess, no single tool that can cover them all. During my fieldwork, he used teacher-created tests, student-created tests, online quizzes, reports, videos, oral presentations, infographics, letters, homework, classwork, lab work, garden work and worksheets for formal assessment. These tools were based on assessment criteria that Barney designed for specific objectives.

A.9.2. Barney's PCK of Scientific Explanation. Introduction

As I exposed in Chapter 2 (§2.6), the study of Pedagogical Content Knowledge offers the opportunity to understand how a teacher can make comprehensible certain concepts and practices, such as the construction of scientific explanations. PCK assumes as a basis the connections between knowledge about General Pedagogy, Subject Matter knowledge, and knowledge of the educational context that the teacher possesses. As for Barney, we find a teacher who has doubts about his Content Knowledge – *"(M)y formative journey has been based, more than on wisdom, on my passion for life*" (I-Ba)– but who recognises having a solid Pedagogical Knowledge (in which he continues to work every day) and an excellent knowledge of his teaching context, especially, the learners.

In the next sections, I make a depiction of Barney's knowledge, beliefs, and practices to guide his students in constructing explanations. First, I analyse Barney's understanding of the concept of scientific explanation, his views on the role explanations play in the scientific enterprise, and his learning goals about this epistemic practice. Secondly, I describe the set of instructional practices Barney used to foster and guide students' attempts to construct explanations. I finish presenting Barney's assessment practices for evaluating students' efforts to explain phenomena.

As I did with all the other participants, I offer one vignette to illustrate the nature of experiences through which Barney's PCK about scientific explanation is made explicit in action (Table A.9.2).

TEACHER	***BARNEY***
VIGNETTE/EPISODE/OBSERVATION	***V#1 / E#1 /Y8.O1-Ba***
TOPIC	***Plagues and plants***

Ba.- Why are there more birds that eat our vegetables during the winter?

S1.- Because they feel attracted by the smell of the plants.

S2.- Because they want to take the pollen from the plants.

Ba.- But, is it now the time for pollen production?

S2.- No, well…, I don't know.

Ba.- Do we currently have any plague in our vegetable garden?

S3.- No... yes, birds!

S4.- Ants...

Ba.- Have the ants caused any harm to your plants? From now on, it is forbidden to kill. The main plague we currently have are the birds. I am going to ask some individual questions, ok? For example, Anne, what do birds eat? Think on a little bird.

S5.- Bird seeds, leaves, ehm.., worms, seeds, ehm…, insects. They eat everything!

Ba.- In which time of the year are there more insects, Albert?

S6.- During the spring.

Ba.- Why? There are two reasons.

S6. Because it is when the plants open.

Ba.- Ok, plants do bloom in springtime, very good. And many insects eat flowers and eat pollen and nectar. But there is another reason…, Andres?

S7. Because the eggs hatch?

Ba.- The eggs hatch… the reproductive cycle of insects is organised in such a way that… why do they have it organised like that?

S8.- For not to die when it's cold.

[Laughs]

keep it at approximately 36-36.5ºC, regardless of the outside temperature. Can an insect do that?

S8.- Yes.

Ba.- We have already studied this. Remember that there are both cold-blooded and warm-blooded animals. (…) Are insects cold-blooded or warm-blooded? Well, I mean, they do not have blood…, do they regulate their temperature, or not? Do you *regulate it? Yes, you do Ba.- Which what percentage of confidence?*

S8-. 0%

Ad.– Oh, wow! let's see…, Angel?

S9.- They do not regulate it. I'm 50% sure.

Ba.- What do an insect have to do to regulate its temperature?

S9.- Get in motion. Stay in the sun.

Ba.- Most insects possess little wings that move… I don't know if you have noticed, but in the springtime, or in the summer, there are much less insects in a cloudy day than in a sunny day. Why, Amanda?

S10.- Because as they do not regulate their temperature, they have to be warm for…

Ba.- The little wings need heat to be able to move, and that heat is taken from the sun. That's why in cloudy and cold days there are not so many insects in the field, even being spring or summer. So, is it insects time now?

Ss.- No!

Ba.- So, the little bird that eats insects and notices that there are no insects now… what can it do?

Ss.- It eats our plants!

Ba.- That's why this is the worst time for [having] plagues of birds that eat our leaves. That's why we have to put plastic bottles to cover our plants, because the birds look for food. Your spines, the well-being of each one of the plants on your spines is an assessable dimension, so that each one here has to manage them so that the bird does not eat his/her plants. And there are people who have plants that birds like a lot, and others who have onions or garlic, bad luck.

Table A.9.2) Vignette #1. Example of explanatory episode in Barney's observed lessons.

A.9.3. Orientation Towards Science (OTS): Barney's knowledge and beliefs about Scientific Explanation

When asked about his conceptualisation of science, Barney commented that this was a "*hyper, mega, super deep question*" that he would be brief in answering because he "*did not know much about it*". His response, however, reflected a profound understanding of some aspects of the nature of the scientific enterprise and the knowledge it produces:

> *"Science is the method that human beings have developed to (…) find a way to approach more, without that being the absolute certainty, to understand everything that happens, not only in the planet, but in the whole universe"* (I-Ba).

Although in this first excerpt Barney speaks of science as a *method*, in singular, he straight away nuanced his words to refer to the existence of a plurality of methods within the different scientific fields:

> *"[T]he scientific methods are not quite developed in the curriculum. But I do try to incorporate them..., especially, scientific methods that have been developed by people I know. If I have the possibility to expose them, analyse them, (…), and bring the person who has developed this method and who is recognised by the scientific community, I believe that children can be closer to that truth that is pursued by those methods."* (I-Ba)

I can reckon that, in this fragment, to what Barney refers is to different research methodologies or procedures that would be specific to each discipline. However, on many other occasions throughout our interview, Barney speaks of *the* scientific method to name to a series of steps that bring scientists closer to an understanding of nature, which can be identified with the so-called hypothetic-deductive method. For Barney, the elaboration of scientific explanations is part of the last step of this method.

In contrast to his somewhat naïve conception of the scientific method, Barney demonstrates having a well-informed understanding of how scientific communities work, and about the social process of construction and validation of scientific knowledge. This is influenced, Barney says, by his belonging to the research community the years he was working in Doñana, and his contact with people who are currently part of that community, like his brother. Barney stresses how relevant it is for scientific progress that scientists collaborate with their peers, either to collect and analyse data or to share their results and concerns –"(scientists) *make suggestions to others, help each other, and give information that otherwise would be* *impossible to be obtained*" (I-Ba). He also mentioned the importance of communicating results, through scientific publications, to the community of experts, so that they can evaluate, discuss, and reach agreements on whether they grant scientific status to what is published.

The tentativeness of scientific knowledge and its social character are key ideas about the epistemological dimensions of NOS, which science researchers and educators consider powerful and effective to improve students' scientific literacy (Bell, 2009; Lederman *et al.*, 2002; Osborne *et al.*, 2003). In his practice, Barney usually incorporates these and other NOS components. Barney strives to create learning environments in which these aspects that go beyond mere conceptual content are integrated, instead of presenting them as separate content. In the interview, he was clear in this regard. He commented that in the National curriculum for each year group, there is always a first chapter entitled 'the scientific method'. According to him, the only thing the teacher is asked to do is "*to tell the students what the method consists of*". But, Barney complaints, "*there is no chapter titled 'developing the scientific method through the topics*". So, he continues, "*it is intended that students know what science consists of without even performing and experiencing it*". This is why Barney "*feel*(s) *compelled to break the curriculum and accommodate these other elements so that (the) students can develop them, since they are probably the most fundamental things to learn about science*" (I-Ba).

For example, in one of his sessions on genetics (Year 11), Barney proposes an activity so that students may experience how to infer empirical laws based on a set of observations. The most relevant for this thesis is, on the one hand, that with this activity Barney aims his students to learn how scientific knowledge is generated; that is, that they delve into the epistemic aspects of science. And, on the other, that for Barney, the learning of science consists of actively and consciously engaging students in different epistemic practices. While the pupils were working in groups, Barney inserted some comments about the real practice of science, so that students might appreciate the differences with respect to working in the classroom.

Table A.9.3.a contains the conclusions about the activity that the different groups presented. These conclusions refer, in most cases, not to the conceptual content acquired, but to what the students have learned about the practical (and epistemic) aspects of science, and about learning itself.

STUDENTS' THOUGHTS ABOUT THE ACTIVITY ON MENDEL'S LAWS
Ba.- I want you to share one of the conclusions of your group. *S1-. Well, we have learned in two classes what he [Mendel] took a long time to learn.* *S2.- I think it has been an interesting way to learn biology more to… in a more entertaining way.* *Ba.- And the third conclusion of your group?* *S3.- That we have brought biology not so much to the class, but more to what can happen in real life.* *S4.- We have learned to deliberate and design a strategy before starting working.* *Ba.- Did you really follow the strategy? Or have you learned that you have to do it?* *S4.- The latter.* *Ba.- So now, when I tell you about the next stage [of the activity], you're going to do it first, right? Strategy. What more things?* *S4.- To move in time, to 1800.* *Ba.- I like it. You're saying everything you're going to do now, right? In other words, now you will work as if we were in 1800 something and also developing a team strategy. I have to see that. Anything else?* *S4-. To reach agreements between us when performing tasks.* *Ba.- Sure! Do you want to say something?* *S5-. That to obtain exact results you have to work for a long time. That is not something fast.* *S6.- We have actually been able to verify the results instead of just learning them by heart.* *Ba.- Of course, you have deduced them, that is what this [activity] is about.* *S7.- We are very lucky to live in these years with so much technology and all we have. That in science you need to have a lot of patience and tenacity.* *S8.- That Mendel was a man who never gave up, because he always wanted more. Every time he found something new, he tried to find out how to do it ...* *Ba.- That is, perseverance is a value in science. Notice that it was hard for you to start counting rice grains. But when you started counting… how long did it take? How much time did you spend? Three minutes, four? You spent 30 minutes saying 'I will not count', and three minutes counting. True or not? Now, when I deliver what is coming after, I hope it is not so.* *S9.- We think that, if something happens to you for the sake of doing, you should… for example, it occurred to us to count rice grains and we said 'no', because we felt too lazy.* *S10.- That experimentation is a very tedious process. And it takes a long time.* *Ba.- Years! Yesterday, when the class finished, I was talking to Elisa about some friends of her who work with bacteria in laboratories, and that is a servitude! Because the bacteria do not understand about bank holidays, or hours, or anything. In other words, you have to be feeding them, and suddenly a bacterial culture that you have been working with for many years is gone; because the temperature has dropped two degrees in the room where you are, or because…, I don't know… but they die. And many times, you don't even know why. There are so many possible variables! Here we are counting rice grains of two different colours, so you can imagine how reality is (…).* *S11.- That we have been able to experience how, over the years, science has evolved a lot.* *Ba.- Anything else?* *S12.- I have forgotten the word ... that we have learned to solve problems in a more ... practical way.* *Ba-. Has your particular group taken any more learning from your experience? Your group tried to falsify data.* *S13.- We have learned to demonstrate a hypothesis.* *S12.- And to falsify data.* *Ba.- (…) Mendel spent years and years and years counting. And based on those numbers ... in fact, a criticism that is made to Mendel is that his results are too ideal. They are too perfect. They conform too much to the theoretical, ideal model. That is a possible criticism. Mendel's critics said that he had falsified the data a bit, as you have done. You have done the same as Mendel, more or less ... count fast. In fact, you have falsified and what has come out? (…) Yes, I know you have repeated it. But what came up before? A too exact proportion. That's just why I knew you had not counted the grains. Now you are correcting it, fine. But that same thing is what Mendel's detractors said he had done.*

Table A.9.3.a) Students' thoughts about the activity on Mendel's laws (Y11.O6-Ba).

The vegetable garden is another scenario that Barney uses to engage students in different scientific practices. The project that Year-8 students would carry out during the second term, about the variables that influence plants' growth, is very enlightening in this regard. Barney frames this project within what he calls the 'scientific method(s)'. His objective is for students to design an experiment and decide which variables they will observe and measure. Through this project, Barney introduces concepts as essential in scientific experimentation as control group, dependent and independent variables, hypothesis, error and sample. Barney provides some guidelines for students to establish connections and differences between the science they do in the school and real-life scientific practice.

> *Ba.- In science, four (instances) is not representative of anything, we should do it with a lot of plants. But anyway, let's do it that way. We take four (plants) in case something happens to any of them. And nothing happens if today, or in the middle of the experiment, some of our plants are shattered or lost, because this happens many times in science.*
>
> *S1.- And in that case, what do we do?*
>
> *Ba.- You redesign your experiment and start again. (Y8.O3-Ba).*

In addition to experimental design, there are other practices in which Barney tries to get his students immersed: the development of arguments and scientific explanations. Barney believes these practices are essential for the proper functioning of science, as they are closely related to how knowledge is constructed and disseminated. However, he thinks they are "*too complex"* for the students (I-Ba).

Barney's dialogic orientation towards teaching science makes him feel attracted by argumentation. He asked me to prepare a workshop on how to argue avoiding fallacies when participating in open-ended discussions (§A.9.1). Long before our workshop, in one class in Year 10, Barney spoke about the importance of producing solid arguments for persuading people. This was not the first time he had introduced this practice explicitly in the classroom. Interestingly, Barney highlighted one of the elements of the Claim-Evidence-Reasoning framework (Berland & Reiser, 2009; McNeill & Pimentel, 2010): Evidence (see §2.5.4). He stated that when crafting an argument, we must "*draw conclusions from the data*" (Y10.O4-Ba). And he adds that, given that data refer to non-debatable facts[8], they can serve as a basis for persuasion.

[8] This is a statement about which there would be much to discuss and qualify.

> *Ba.- What arguments can I use to tell someone who is afraid and who said he would never do it (travelling alone) in his life? What is the best argument? Do you remember what we talked about opinions and facts? What is the way to show someone who has these fears that they are unfounded?*
>
> *S1.- With data.*
>
> *S2.- There are statistics.*
>
> *Ba.- We have numbers, facts, and opinions, right? A number is almost non-debatable. When you measure something, like the number of deaths, that is not debatable, it is a fact (Y10.O2-Ba).*

Students working with data (what he calls 'numbers') is one constant in Barney's classes at all educational levels; in some cases, this is related to the introduction of explanations. As I said at the beginning of this section, for Barney, one of the objectives of scientists is to "*understand everything that happens (…) in the universe*" (I-Ba). He considers that data provide us with an objective measure of what is happening (what he calls the 'facts'), and if we are able to interpret them, we could reach a certain level of comprehension.

Constructing explanations to make sense of a set of data is the most common meaning Barney attributes to this practice, but it is not the only one. Barney does use the word 'explain' to refer to actions as varied as the justification of an answer/belief, the justification of a procedure, and the search for causes that account for why a phenomenon occurs. To this, we must add a category that relates only to the data collected in only Barney's case, which fits with his target that students learn aspects related to the Nature of Science: to explain the reasons why there is a difference between theoretical and empirical results. That is, within the 16 episodes I categorised as 'explanation construction' in Barney's practice, I found both scientific (causal/mechanistic, evolutionary, teleological) and non-scientific (justificatory) explanations. Within those episodes in which Barney asked the students to *explain* certain point in a graph or a datum shown in a statistical document, we can find 'scientific explanation seeking' episodes (since Barney aims for the students to justify or interpret the data according to some known scientific theory, model or concept), while others have been classified as non-scientific (for instance, when the justificatory reasons are of a historical nature, (E#13-Ba)). In Table A.9.3.b, there are examples for each of the different meanings Barney displays for 'explanation'.

Of the 16 episodes recorded during my stay with Barney, only two were initiated by students. In Episode #3, a student asks Barney why snails come out when it rains. To this question, a second student gives a teleological explanation – *"Because they are sluggish and* *crawl through the water"* (E#3-Ba). Barney does not make any comment about this answer. It would have been interesting, though, to say something about this type of explanations, in which the consequences are usually confused with the antecedents (Talanquer, 2007), or there is an over-attribution of intentionality (Grotzer, 2003). In Episode #7, we find a student who provides an evolutionary explanation, but Barney demands another type of explanation, concretely, a mechanistic explanation –"*Ok, that's the evolutionary sense, but why does that change happen suddenly?* (E#7-Ba). This episode illustrates the dichotomy defended by Mayr (1961) between evolutionary/ultimate explanations and functional/proximate explanations. According to this author, evolutionary explanations respond to why-questions that may be summarised as 'how did the phenomenon come to be, in the light of evolution?' (van Mil *et al*., 2013). In contrast, functional explanations provide a causal-mechanistic account about developmental and physiological processes (Ariew, 2003); they answer questions of the type 'how does something function?'. This episode evidences that Barney can distinguish these two types of explanations.

In the second episode initiated by a student (E#4-Ba), Barney relates three different practices within the so-called POE teaching sequence (White & Gunstone, 1992): Prediction-Observation-Explanation. Unfortunately, in the time that I was conducting my observations in School-B, Barney and his students had just started the project on plants growth, so I could not get to know what types of strategies Barney would use to implement the POE teaching sequence. However, this fragment suggests that, for Barney, at least one meaning of 'explaining' involves the articulation of knowledge to make sense of an observed phenomenon, which fits into my operational definition of explanation.

Table A.9.3.b) Barney's different meanings for 'explanation'

TYPE OF EXPLANATION	*EXAMPLE*
SCIENTIFIC EXPLANATION	**Articulation of theoretical and background knowledge to make sense of a certain phenomenon through a process of reasoning**
Causal	*Ba.-I know the plants do not need milk, but hey, if you want to pour milk every Thursday, it seems good. I do not know what will happen, but what is your hypothesis? What do you think will happen?* *S1.- I think it's going to be fine, because my mother uses it in my house.* *Ba.- And what happens?* *S1.- Well,* ***when the leaves become faded and they fall, then they grow back.*** ***Ba.- Why?*** ***S1.- I don't know.*** ***Ba.- Well, that's what I want you to know*** (E#4; Y8.O3-Ba)
Mechanistic vs Evolutionary	*Ba.- Why does, suddenly, some physical changes occur on your body that had not occurred before? Why?* *S1.- Because the level of hormones increases.* *Ba.-* ***And why does the level of hormones increase at a certain time of your development?*** *S2.-* ***Because that prepares you to become a mother or a father.*** *Ba.-* ***Ok, that's the evolutionary sense, but why does that change happen suddenly? What happens in the body that causes that level of hormones to increase?*** *Who does produce the hormones? Where are they produced?* *S3.- In the brain.* *Ba.- Not only in the brain, but also in the gonads. But their release depends on two other hormones that have been previously released in the brain. We spoke about two especially, although there are many more: dopamine and oxytocin. Dopamine has many effects on the body.* (E#7; Y10.O1-Ba)
Teleological explanations	*Ba.- The eggs hatch… the reproductive cycle of insects is organised in such a way that… why do they have it organised like that?* *S8.-* ***For not to die when it's cold*** (E#1; Y8.O1-Ba)
Make sense of a set of data	*Ba.- If we relate it to everything we have seen about the development of the brain and the hormones,* ***do you find any sense that in boys between 15 and 19 years the first cause of death is traffic accidents, and in girls, the first cause of death is suicide?*** *S1.- In boys, because of the hormone that makes them see the reward more than the risk… Then, maybe they go fast because of having that adrenaline, or something, and they take the risk and they do not know ...* *Ba.- That is.* ***It should be studied scientifically, but surely there is a correlation between the level of hormones, that hormone that exposes you more to the challenges, and the number of traffic accidents. Because in other age bands it does not happen. It coincides with the age range in which the levels of that hormone are higher.*** *We also saw that brain development does not end until 24-25 yearsE2.- Well maybe with the hormone that makes you have feelings more..., that is, that things affect you more.* (E#14; Y10.O6-Ba)

Table A.9.3.b) Barney's different meanings for 'explanation'

NON-SCIENTIFIC EXPLANATIONS	Different meanings
Make sense of a set of data	*Ba.- (…) You see that here, suddenly and beastly, because it is brutal, around 1918 life expectancy dropped a lot. I want you to tell me what happened. And here there is another great downhill. I want you to tell me now why. You have to research about this on the fly. Do not make it up; I want you to investigate and tell me.* *Who has something?* ***Who knows how to explain this little dot here?*** *S1.- The First World War.* *Ba.- No.* *S2.- It was an epidemic. The 1918 influenza pandemic.* (E#13; Y10.O4-Ba)
Justifying a procedure	*Ba.- What do we have to do before the sowing?* *S1.- We have to stir the soil.* ***Ba.- Why do we have to do that?*** *S2. For it to aerate.* *S3. For it to oxygenate.* *Ba.- For it to oxygenate,* ***why?*** *S4.- For plants to have enough nutrient.* (E#2; Y8.O1-Ba)
Justifying an answer/belief	*Ba.- I would like to invite you to reflect. You said that [lettuce] can be seeded practically at any time. We're going to take advantage of the fact that he has commented on that to ... uh, in fact, we do it here, don't we? We seed it at any time. We have this planted and it is growing well, the lettuce.* ***Why do you consider it important that you can seed lettuces at any time?*** *S1.- So that we have more lettuce.* (E#6; Y8.O8-Ba)
Explain the difference between theoretical and practical result	*Ba.-* ***Why does this datum -73%- come out? Does it correspond to what you know?*** ***S1.- Well, not exactly.*** ***Ba.- Not exactly, why?*** *S1.- Because we do not have a very large sample.* ***Ba.- Why is there not a match between the data we find in nature and the numerical ideal we already know?*** *What factors alter that ideal number? There are many possible.* *S2.- The sample could get broken. There are rice grains that were ...* *A.- This happens in real life. For sure, some of Mendel's peas were overripe. What else?* ***Why these are not the ideal proportions****? (*(E#16; Y11.O5-Ba)

Due to unexpected changes in his agenda, I had to interview Barney once I had finished my fieldwork at School-B. Before the interview, then, I had already transcribed a small part of my data. I had noticed that in Barney's classes, the term 'explain' had been used with many different meanings. I order to understand was this term meant for him, I asked Barney directly what a scientific explanation is. His first sentence when responding showed this was an issue on which he had already reflected:

> *"I know that not everyone thinks the same about what a scientific explanation is. Even if you search on the Internet what the official notion of scientific explanation is, not everyone agrees; it is not trivial, you know?"* (I-Ba)

After this, Barney said that "*explaining in science*" means "*to elaborate the results of scientific research in order to make them understandable to a non-expert public*" (I-Ba). Although this characterisation of explanations in science is clear, it does not match with any of the meanings with which Barney used the verb 'explain' in his classes. In another moment, Barney states that "*the scientific method is the way (...) we have to turn a scientific phenomenon into a theory, explaining it so that it can be understood"* (I-Ba). Leaving some epistemic inaccuracies aside, this new characterisation reinforces the first but adds a nuance: it appeals to theories as explanatory elements of the phenomena. This is significant, because it reflects that Barney knows some of the elements necessary to construct a scientific explanation. That he is fully aware of these elements is debatable, though, because, contrary to what happens with the construction of arguments –for which he explicitly states that claims must be backed on by facts– in those episodes in which Barney asks the students to build explanations, he never mentions the need to use data and/or theoretical models or concepts.

A.9.4. Barney's Knowledge of Instructional Strategies (KIS)

As seen with the previous participants, there are distinctive forms and communication patterns through which teachers and students may interact in science classrooms. These interactions are usually conducted deliberately by the teacher with a purpose on mind. In the episodes I analysed, Barney engaged in dialogical interactions to get students to explain and, consequently, understand, certain phenomena, beliefs, or data. These interactions were part of a set of teaching strategies that Barney implemented to address the different ideas that emerged during an explanation construction process. I codified them under the four-categories framework that Mortimer and Scott (2003) proposed (see Figure 3.7.2.b).

In the 16 observed episodes, Barney uses an Interactive communicative approach, allowing for the participation of different students in the conversation. It makes sense since, as we have seen, Barney's classes are full of opportunities for teacher-student and student-student dialogues. Barney claims to be interested in knowing what students think, so, it is not surprising that half of the explanatory episodes have a Dialogical character (Table 4.9.4.a): the students can propose their ideas and views, and these are taken by Barney as the guiding thread of the construction process. In this sense, Episode #12 is very illuminating. Barney dedicates something more than 10 minutes for a student to tell the rest of the class the explanation she has developed for the variations that exist in life expectancy in different countries –"*Bianca is very interested, and so am I, in talking about life expectancy (…). What do you want to comment on, Bianca? (…) Why do you think life expectancy is those countries are those?* (E#12-Ba).

Something characteristic of Interactive/Dialogic episodes is that, in them, Barney recognises that the explanation they are proposing, although sensible, is not necessarily the correct one (E#14-Ba). This language accentuates the non-authoritarian character of these episodes, which could help students understand that the teacher is not the absolute epistemic authority. Although Barney did not note it, these episodes could also be used to enculturate students in certain aspects about the nature of the scientific enterprise (the underdetermination of explanatory theories by evidence, the constant doubt that accompanies research, the need to establish explanations for the patterns found, the importance of finding consensus within the doubt, etc.).

There are seven episodes I classified as Interactive/Authoritative (Table A.9.4.a), since Barney tries to guide students towards a specific response or perspective. In these cases, he uses less ambiguous expressions, more closed-questions and a more authoritative tone of voice (E#8-Ba), ignores some students' intervention (E#2-Ba), and corrects the students (E#9-Ba). Sometimes, he even provides his explanation for the phenomenon under analysis (E#5-Ba).

This duality in Barney's interactive discourse reflects a duality of purposes; sometimes Barney wants students to acquire some canonical knowledge, while at other times, what interests him most is that the students reflect, reason, relate different pieces of knowledge and/or develop their communicative skills (E#11-Ba). Scott (1998) suggests that fluctuating in a balanced and coherent way between an authoritative discourse –stressing the already-produced knowledge– and a dialogical approach –allowing students' to explore and share some new ideas– may have a positive impact on learning.

COMMUNICATIVE APPROACH	EPISODES	EVIDENCE
Interactive/ Authoritative	1; 2; 5; 8; 9; 11; 13;	*Ba.- How would you explain that? I'm always going to ask you why you think that data are like that. This is a tendency that always occurs ... what do you think can be attributed to the fact that there are more deaths each year?* *S1.- To drugs.* ***Ba.-To drugs? Do you think that there are more drugs year by year?*** *S1.-No, but every time [people] hook on earlier.* *S2.- Or that every time there are more drunkards that take the car ...* ***Ba.- But are there more and more drunkards? That is not ..., what are you based on?*** *On the contrary, the government proposes progressively more measures, and we are progressively more aware of many things that happen ... then, why is there this increase?* *S3.-Well, maybe because of a big fire ... in a fire people can die ...* ***Ba.- Is there a super fire every year?*** *S3.-No, but, that is ...* *S4.- More people die every year because there are more and more people.* *Ba.-**That's it!** There are more and more people in Spain, that's why more and more people die every time.* (E#8; Y10.O3-Ba)
Interactive/Dialogic	3; 4; 6; 7; 10; 12; 14; 16	*Ba.- In other words, you say that there are two ways [for the products] to reach the supermarket despite not being their time: one, altering them genetically, that is true. In Spain there is not much of that now, but well, there is a debate. And another way is by importing them. What are the consequences of both? Why is it better to consume what has been locally ...?* *S6.- Because your country is going to earn more.* ***Ba.- OK, that's an argument: I want to boost the economy of my country, and I buy products from my country. It's not where I was trying to go, but** ... (E#6; Y8.O8-Ba)*
Non-interactive/ Authoritative	----------	----------
Non-interactive/ Dialogic	----------	----------
Non-classifiable	15	*Ba.- We already know, because we know genetics, that this has a genetic explanation. You know today more than Mendel. Mendel spent his life studying this, because today you come here, and you already know more than him. Tell me the genetic basis of that law.* (E#15; Y11.O4-Ba)

Table A.9.4.a) Barney's communicative approach for the episodes on explanation

In Barney's lessons, then, the only type of activity in which the construction of explanations appears are dialogues in which the interventions focus on the construction and application of knowledge and the elaboration of reasoning, rather than simply reproducing information already known. All the episodes I witnessed are examples of joint oral construction of explanations (Table A.9.4.b). In none of the observed lessons, Barney asks the students to write an explanation, neither does he ask them to work in small groups or pairs. In one case (E#13-Ba), students had to think of an explanation individually, but after some minutes, they did share and discuss it with the rest of the class. Thus, the only activity that can be talked about in Barney's practice is dialoguing, either with the whole class (that is, with different students taking part in the dialectical exchange) or with only one student (while the others listen).

TYPE OF ACTIVITY	EXAMPLES
Whole-class dialogue	*Ba.- Why does, suddenly, some physical changes occur on your body that had not occurred before? Why?* *S1.- Because the level of hormones increases.* *Ba.- And why does the level of hormones increase at a certain time of your development?* *S2.- Because that prepares you to become a mother or a father.* *Ba.- Ok, that's the evolutionary sense, but why does that change happen suddenly? What happens in the body that causes that level of hormones to increase? Who does produce the hormones? Where are they produced?* *S3.- In the brain.* *Ba.- Not only in the brain, but also in the gonads. But their release depends on two other hormones that have been previously released in the brain. We spoke about two especially, although there are many more: dopamine and oxytocin. Dopamine has many effects on the body.* *S4.-One is that the reward is greater than the risk, you value it more.* *Ad-. It activates more reward circuits in the brain ... and what consequences does it have on a teenager's brain?* *S3.- That they risk more than an adult and do not think about the consequences.* (E#7; Y10.O1-Ba)
Teacher-Student dialogue	*Ba.- (…) Why do you think life expectancy is those countries are those?* *S6.- Well, from my point of view, and from what I have researched, these differences are due to the food of each country and the diets people follow. Because, for example, the Internet shows that the diet of the Japanese is very good.* *Ba.- One of the factors that makes it so is the type of food. Something that one can modify at will. This is very important.* *S6.- The conflicts that exist or have existed in that country, such as in Sierra Leone, has also a strong influence.* *Ad.- Ok, the general state of the country. (…)* (E#12; Y10.O4-Ba)

Table A.9.4.b) Types of activities present in Barney's episodes on explanation.

The analysis of Barney's specific discourse moves may help us understand how he engages students in the process of elaborating an explanation. In almost all the observed occurrences (except for Episodes #3 and #4), Barney opens the episode trying to engage students intellectually and emotionally (Table A.9.4.c). To do so, he addresses the students by asking for their opinions (E#9-Ba; E#10-Ba) and reflections (E#6-Ba), asking what has caught their attention (E#8-Ba), what they want to talk about (E#12-Ba), or referring to something a student has mentioned before (E#5-Ba). Another strategy that Barney implements is to send someone a direct question, of a rather open nature, that initiates a dialogue in which others are invited to participate (e.g., E#1-Ba, E#7-Ba, E#16-Ba). These initial questions allow Barney to inquire into students' views and understandings about the phenomenon they want to explain.

The opening question is usually followed by a battery of related questions or comments to work out on students' views. More specifically, these questions and comments may have two different purposes: either they are designed for the students to interpret, delve into and/or elaborate their own or their peers' reasoning, or they are intended to bring in new perspectives which expand the joint explanation. The first group refers to what I have coded here as 'Continuing moves', within which we find explicit invitations to elaborate the reasoning (E#7-Ba), to specifying some idea by means of examples (E#7-Ba), connections (E#10-Ba; E#14-Ba) or predictions (E#4-Ba), and, more commonly, the guiding questions (e.g., E#1-Ba; E#3-Ba; E#6-Ba; E#16-Ba).

Other interventions to maintain the development of the scientific explanation are coded under the label 'Extending moves'. In these cases, Barney provides some keys so that the process of constructing the explanation can proceed in the direction in which he is interested. Following Moreira, Marzabal and Talanquer (2019), it can be said that Barney i) Shapes meaning: he paraphrases students' responses and adds some information (E#6-Ba, E#7-Ba); ii) Selects meanings: he ignores/rejects a student's intervention while considers or prompts other's contributions (E#2-Ba, E#3-Ba). He also may ignore a wrong answer to provide the correct one (E#6-Ba) and/or repeat a student's idea with an interrogative tone to show his disagreement (E#8-Ba); and iii) Marks key meanings: he repeats a statement in a positive/neutral tone (E#16-Ba), engages in a rhetorical questioning to highlight an idea (E#13-Ba) and/or notes that one student's idea is a misconception (E#1-Ba). A move that Moreira and collaborators do not include is to redirect the discussion: he presents a completely new topic/perspective (E#6-Ba). Thanks to all these communicative moves, Barney manages to channel the direction of the discourse and to avoid dispersion, which corresponds to what characterises authoritative approaches (Scott *et al*., 2006). Another strategy I decided to include under the continuing moves was 'Challenges degree of certainty'. Perhaps asking a respondent how sure she is of her contribution does not seem an invitation to extend it: But since it is an invitation to reflection, it might lead the student to try to interpret what is being said from a new perspective, and with it, deepening her understanding. For example, in Episode #1, when a student says his percentage of confidence in his answer is 0%, another student decides to intervene in the conversation, contributing to the reasoning process did not stop (E#1-Ba).

To encourage students, Barney uses two types of moves: Reinforcing and Referring moves. For the first, he utters some personal remarks or evaluative comments in the course of the explanation development. When he makes a positive comment, recognises the relevance of an intervention or shows his agreement with the student's contribution, Barney changes the tone of his voice, to sound more enthusiastic. This usually helps students feel more confident to continue participating in the dialogue. Another way of capturing students' interest is to establish links between the phenomenon under explanation with some knowledge that they already have, or with their realities outside the classroom. This communicative act seems to respond to Barney's purpose of connecting all the curriculum with his students' life (§A.9.1).

Barney's explanatory episodes were long and complex; in them, many different ideas and phenomena intertwined on the way. It is, then, somewhat surprising that Barney's concluding moves are not aimed at summarising the ideas that have appear during the development of the explanation, but to remark the last contribution. This last contribution is paraphrased or repeated without further ado; with it, more than being a single account, the episodes turn out to be a sequence of responses to seeking-why questions. Only in some cases, Barney refers back to the opening question, which brings coherence and unity to the episode (E#1-Ba). In Interactive/Dialogic episodes (e.g., E#10-Ba), Barney does not close the explanation categorically, which might be understood as an attempt to dilute his epistemic authority as the teacher (Berland & Hammer, 2012).

Table A.9.4.c) Discourse moves present in Barney's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy* **et al., 2016*), and Kaartinen and Kumpulainen (2002).

BARNEY'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		**EXAMPLES**
Initiating moves	Direct instruction (new problem)	***Ba.- I want you to do it on your screens, and I'm going to ask you two very important questions; all of you, look at here. You see that here, suddenly and beastly, because it is brutal, around 1918 life expectancy dropped a lot. I want you to tell me what happened. And here there is another great downhill. I want you to tell me now why. You have to research about this on the fly. Do not make it up; I want you to investigate and tell me.*** *Who has something? Who knows how to explain this little dot here?* *S1.- The first world war.* (E#13; Y10.O4-Ba)
	Invites reflection	***Ba.- I would like to invite you to reflect***. *You said that [lettuce] can be seeded practically at any time. We're going to take advantage of the fact that he has commented on that to ... uh, in fact, we do it here, don't we? We seed it at any time. We have this planted and it is growing well, the lettuce. Why do you consider it important that you can seed lettuces at any time?* *S1.- So that we have more lettuce.* *[Laughs].* *Ba.- I think the question is not well posed, but well, I now reformulate it. Anne Laura?* (E#6; Y8.O8-Ba)
	Casts/recalls students' attention	***Ba.- What has caught your attention in this document?*** *S1.- The increase in the number of deaths with respect to the previous year. It is weird that there is so much variation from one year to the next, both in boys and girls.* *Ba.- How would you explain that? I'm always going to ask you why you think that data are like that. This is a tendency that always occurs ...* (E#8; Y10.O3-Ba)
	Reasoning Question	**Ba.- Why are there more birds that eat our vegetables during the winter?** S1.- Because they feel attracted by the smell of the plants. S2.- Because they want to take the pollen from the plants. (E#1; Y8.O1-Ba)
	Asks for an opinion	*S1. From the age of 30, as [people] get older, there are fewer deaths due to external causes.* ***Ba.- Why? Now I'm going to ask for your opinion. Why most people who die due to external causes are in that age group?*** *S1.- because at that age they take more risks*. (E#10; Y10.O4-Ba)
	Addresses a particular student's interest	**Ba.- *Bianca is very interested, and so do I, in talking about life expectancy*** *(in fact, this is what I was going to talk about now and compare it between different countries). What do you want to comment on, Bianca? (…)* ***Why do you think life expectancy is those countries are those?*** *S6.- Well, from my point of view, and from what I have researched, these differences are due to the food of each country and the diets people follow. Because, for example, the Internet shows that the diet of the Japanese is very good.* (E#12; Y10.O4-Ba)

Table A.9.4.c) Discourse moves present in Barney's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy **et al., 2016)*****, and Kaartinen and Kumpulainen (2002).***

BARNEY'S INTERVENTIONS (DISCOURSE MOVES)		EXAMPLES
Initiating moves	Asks for a connection to prior knowledge	*Ba.- Why does this datum -73%- come out?* ***Does that correspond to what you know?*** *S1.- Well, not exactly.* *Ba.- Not exactly, why?* *S1.- Because we do not have a very large sample.* (E#16; Y11.O5-Ba)
	Refers to a prior intervention	***Ba.- You have mentioned the whole wheat there; do you know what it is? What is the difference between whole wheat and non-whole or refined wheat?***(E#5; Y8.O6-Ba)
Continuing moves	Repeats with an interrogative tone	*Ba.- How would you explain that? I'm always going to ask you why you think that data are like that. This is a tendency that always occurs ... what do you think can be attributed to the fact that there are more deaths each year?* ***S1.- To drugs.*** ***Ba.-To drugs?*** *Do you think that there are more drugs year by year?* *S1.-No, but every year [people] hook on earlier.* *S2.- Or because every year* ***there are more drunkards that take the car ...*** ***Ba.- But are there more and more drunkards?*** *That is not… what re you based on? On the contrary, the government proposes progressively more measures, and we are progressively more aware of many things that happen... then, why is there this increase?* ***S3.-Well, maybe because of a big fire ... in a fire people can die ...*** ***Ba.- Is there a super fire every year?*** *(…)* (E#8; Y10.O3-Ba)
	Repeats a statement and adds some information	*Ba.- This happens in real life. For sure, some of Mendel's peas were overripe. What else? Why these are not the ideal proportions?* ***S3.- Because there are mutations.*** ***Ba.- Because there are mutations****, we already know that there are. Or, maybe, it comes a bird who likes more white grains than yellow ones and eats them, I do not know. There are a lot of variables in nature that occur. What is done in science to counteract all these variables?* ***S4.- Do it many times.*** ***Ba.- Do it many times****. The more times, the more volume of data I have, the more I will approach the ideal proportions. (…)* (E#16; Y11.O5-Ba)

Table A.9.4.c) Discourse moves present in Barney's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy* et al., 2016*), and Kaartinen and Kumpulainen (2002).

BARNEY'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		**EXAMPLES**
Extending moves	Ignores a student's intervention	*Ba.- What do we have to do before the sowing?* *S1.- We have to stir the soil.* *Ba.- Why do we have to do that?* *S2. For it to aerate.* *S3. For it to oxygenate.* ***Ba.- For it to oxygenate, why?*** ***S4.- For plants to have enough nutrient.*** ***Ba.- But why do we have to oxygenate the soil?*** *Through where do the plants take most of the material that will build them and make them grow from the little seed they were?* (E#2; Y8.O1-Ba)
	Sets a new topic/ perspective	Ba.- And what does that originate? S4.- That there may be tomato at all times of the year. **Ba.- And now, if we talk about responsible consumption, what information should we have so that our way of consuming food is the least harmful to the land or to the environment?** How does that affect, Arantxa? S5.- We should know when the season of each thing is. Because many times they are not planted in other countries, but they change their DNA, or with chemical products to help [the plants] grow, but it's always going to be better to eat them from your garden. (E#6; Y8.O8-Ba)
	Offers an additional answer	*Ba.- This happens in real life. For sure, some of Mendel's peas were overripe. What else? Why these are not the ideal proportions?* *S3.- Because there are mutations.* *Ba.- Because there are mutations, we already know that there are.* ***Or, maybe, it comes a bird who likes more white grains than yellow ones and eats them, I do not know. There are a lot of variables in nature that occur****.* (E316; Y11.O5-Ba)
	Ignores a wrong answer and provides the correct one	Ba.- Okay, yes, do you know why? What has the whole wheat that the other does not have? Or rather, what does not have the other, the refined one...? Who knows? **S2.- I do not know, but I think that the refined one has this sort of peel…** **Ba.- There is a layer (...). If you take the grain of wheat, it has a first layer, and in the refining process, it is removed, right?** That first layer is fibre, fundamentally. That is why it is said that the whole is very good for the digestive (E#5; Y8.O6-Ba)

Table A.9.4.c) Discourse moves present in Barney's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy* et al., 2016)*, and Kaartinen and Kumpulainen (2002).

BARNEY'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Extending moves	Rephrases and adds information	*Ba.- And now, if we talk about responsible consumption, what information should we have so that our way of consuming food is the least harmful to the land or to the environment? How does that affect, Arantxa?* *S5.- We should know when the season of each thing is. Because many times they are not planted in other countries, but they change their DNA, or with chemical products to help [the plants] grow, but it's always going to be better to eat them from your garden.* *Ba.- In other words, you say that there are two ways to reach the supermarket, although it is not their time: one, altering them genetically, that is true. In Spain there is not much of that now, but well, there is a debate. And another way is by importing them. What are the consequences of both? Why is it better to consume what has been locally ...?* (E#6; Y8.O8-Ba)
	Notes a misconception	*Ba.- But why do we have to oxygenate the soil? Through where do the plants take most of the material that will build them and make them grow from the little seed they were?* ***S5.- Trough the root****…, from the air, from the carbon dioxide…* ***Ba.- That's a very extended misconception, isn't it? "Plants are fed by the roots"; no. The plant…, most of the carbon that is used as building material for the plant comes from the CO2 that is around here.*** *What does it take from the root?* *Ss.- Nutrients.* (E#2; Y8.O1-Ba)
	Challenges degree of certainty	*Ba.- We have already studied this. Remember that there are both cold-blooded and warm-blooded animals. (…) Are insects cold-blooded or warm-blooded? Well, I mean, they do not have blood…, do they regulate their temperature, or not? Do you regulate it? Yes, you do keep it at approximately 36-36.5ºC, regardless of the outside temperature. Can an insect do that?* *S8.- Yes.* ***Ba.- Which what percentage of confidence?*** ***S8.- 0%*** ***Ad.– Oh, wow! Let's see…, Angel?*** ***S9.- They do not regulate it. I'm 50% sure****.* (E#1; Y8.O1-Ba)
	Rhetorical questioning	*Ba.- (…) Are insects cold-blooded or warm-blooded? Well, I mean, they do not have blood…, do they regulate their temperature, or not?* ***Do you regulate it? Yes, you do keep it at approximately 36-36.5ºC, regardless of the outside temperature****. Can an insect do that?* *S8.- Yes*. (E#1; Y8O1-Ba) ***Ba.- What is a pandemic? A huge epidemic which affects a large part of the world's population; it is not local.*** *This epidemic was called 'the Spanish flu' because, as she says, many countries were at war and in Spain there was more freedom of information, in the newspapers, then they published it. But it is not that more people died in Spain*. (E#13; Y10.O4-Ba)

Table A.9.4.c) Discourse moves present in Barney's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy* et al., 2016*), and Kaartinen and Kumpulainen (2002).

BARNEY'S INTERVENTIONS (DISCOURSE MOVES, COMMUNICATIVE ACTS)		EXAMPLES
Referring moves: Makes explicit links to	Student's reality	*S3.- For example, with regard to suicide, as in adolescence you are more affected by the comments of people of your same age, maybe what they say affects you in another way, in an exaggerated way, and that takes you to suicide.* *Ba.- It might make sense, because we have seen that one of the functions of the frontal lobe, which is the one that takes longer to develop... do you remember what its function is?* *S4. Planning and problem solving.* ***Ba.- This is very important, because at your age the problems are the biggest in the universe, and then you realise that they are not so big. And that could be related to the way in which one faces the problems that arise in one's life. At your age it is not fully developed to undertake this**... it makes sense, although I do not know if it is related to this.* (E#10; Y10.O4-Ba)
	Prior knowledge	*Ba.- The eggs hatch… the reproductive cycle of insects is organised in such a way that… why do they have it organised like that?* *S8.- For not to die when it's cold.* *[Laughs]* ***Ba.- We have already studied this. Remember that there are both cold-blooded and warm-blooded animals.*** (E#1; Y8.O1-Ba)
Commenting/reinforcing moves	Makes a positive comment	*S2.- Another assumption is that, as in this age group, it affects you more ..., that is, how was all that about the social pressure? So, if you receive negative comments, they can affect you more…* *A.- It could be linked to all that.* ***Very well!*** (E#14; Y10.O6-Ba)
	Recognises the value of an intervention	*Ba.- (…) Why do you think life expectancy is those countries are those?* *S6.- Well, from my point of view, and from what I have researched, these differences are due to the food of each country and the diets people follow. Because, for example, the Internet shows that the diet of the Japanese is very good.* *Ba.- One of the factors that makes it so is the type of food. Something that one can modify at will.* ***This is very important**.* (E#12; Y10.O4-Ba)
	Shows agreement	*S6.- And, of course, the health system of each country, since, if there is any disease, you must have the medication or the treatment to cure it.* ***Ba.- Totally true.*** (E#12; Y10.O4-Ba)

Table A.9.4.c) Discourse moves present in Barney's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy* et al., *2016), and Kaartinen and Kumpulainen (2002).

BARNEY'S INTERVENTIONS		EXAMPLES
Continuing moves	Asks for examples	*Ba.- Why do more people in Asturias die from diseases related to the circulatory system?* *S5.- For their life habits.* ***Ba.- What, for example?*** *S5.- they eat a lot of pork. Chorizo, morcilla ..., things with a lot of fat*. (E#11; Y10.O4-Ba)
	Poses chained questions	*Ba.- Why does, suddenly, some physical changes occur on your body that had not occurred before?* ***Why?*** ***S1.- Because the level of hormones increases.*** ***Ba.- And why does the level of hormones increase at a certain time of your development?*** *S2.- Because that prepares you to become a mother or a father.* (E#7; Y10.O1-Ba)
	Poses guiding questions	*Ba.- What is the difference between whole wheat and non-whole or refined wheat?* *S1.- The whole is healthier.* *Ba.- Yes, but the difference in the grain. If you know why one is called 'whole' and the other is not.* *S1.- Well, the whole is like brownish.* *Ba.- Okay, yes, do you know why? What has the whole wheat that the other does not have? Or rather, what does not have the other, the refined one...? (…)* (E#5; Y8.O6-Ba)
	Asks for predictions	*Ba.-I know the plants do not need milk, but hey, if you want to pour milk every Thursday, it seems good****. I do not know what will happen, but what is your hypothesis?*** ***S1.- I think it's going to be fine, because my mother uses it in my house*** (E#4; Y8.O3-Ba)
	Asks for connections with prior knowledge	*S1.- Because at that age they take more risks.* ***Ba.- Can we relate that to something we have learned about the brain? With what?*** *S2.- With oxytocin. More teenagers die because they take more risks because oxytocin levels in their brain increase and one of the effects is that ... [they] value the reward more than the risk*. (E#10; Y10.O4-Ba)
	Reasoning Question (restricting the number of options)	*Ba.- In which time of the year are there more insects, Berto?* *S6.- During the spring.* ***Ba.- Why? There are two reasons.*** *S6. Because it is when the plants open.* *Ba.- Ok, plants do bloom in springtime, very good. And many insects eat flowers and eat pollen and nectar.* ***But there is another reason…, Boris?*** *S7. Because the eggs hatch?* *Ba.- The eggs hatch… the reproductive cycle of insects is organised in such a way that…* (E#1; Y8.O1-Ba)

Table A.9.4.c) Discourse moves present in Barney's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy* et al., *2016), and Kaartinen and Kumpulainen (2002).

BARNEY'S INTERVENTIONS		EXAMPLES
Continuing moves	Invites elaboration	*Ba.- What evolutionary sense does that have?* *S5.- The reproduction.* ***Ba.- Expound on it a bit more.*** *S5.- Well, by spending more time with your peers, you can end up with a girl and breeding*. (E#7; Y10.O1-Ba) *Ba.- What do you think will happen?* ***S1.- I think it's going to be fine, because my mother uses it in my house.*** ***Ba.- And what happens?*** *S1.- Well, when the leaves become faded and they fall, then they grow back*. (E#4; Y8.O3-Ba)
Concluding moves	Provides the desired answer	*S2.- I do not know, but I think that the refined one has this sort of peel…* *Ba.- There is a layer (...). If you take the grain of wheat, it has a first layer, and in the refining process, it is removed, right? That first layer is fibre, fundamentally. That is why it is said that the whole is very good for the digestive tract. The fibre, what it does in the intestine, in the intestines, is that it facilitates the passage of food through the intestines, so that it regulates very well everything that has to do with the peristaltic movements that lead the food through the tube. This is very good, okay? Most of the food we eat that come from cereals come from refined grains that have had this first layer removed, right? Now at least we know…, because we always heard people say: "the integral is better", but we did not know why. Now you know that it is because it has fibre, and fibre is very good. Today, wholemeal food is in fashion, but a few years ago it was not so common. The first layer was removed from everything. Today, as it has been seen that it is beneficial for... besides, a good thing that fibre has is that it gives you a feeling of satiety, and you eat less when you eat something whole. Fibre…, we do not have bacteria, nor digestive enzymes to digest fibre* (E#5; Y8.O6-Ba)
	Recognises his ignorance	*S1.- Why do the snails go out when it rains?* *S2.- Because they are sluggish and crawl through the water.* ***Ba.- Well I do not know exactly; I should think about it.*** (E#3; Y8.O1-Ba)
	Repeats the last idea and adds some information	***S4.- More people die every year because there are more and more people.*** ***Ba.-That's it! There are more and more people in Spain, that's why more and more people die every time.*** *In fact, we are in a stage of exponential growth of the human population. Do you know how many inhabitants there are on the planet, more or less? Between 7,000 and 8,000 million, very well. (E#8; Y10.O3-Ba)*
	Remarks a misconception	***Ba.- That's a very extended misconception, isn't it? "Plants are fed by the roots"; no.*** *The plant…, most of the carbon that is used as building material for the plant comes from the CO2 that is around here. What does it take from the root?* *Ss.- Nutrients.* *A.- Minerals and nutrients,* ***but not most of the material that constitutes it, right?*** (E#2; Y8.O1-Ba)

Table A.9.4.c) Discourse moves present in Barney's episodes on explanation. Adapted from the analytical framework of Mortimer and Scott (2003), the SEDA project (Henessy* **et al., 2016)**, and Kaartinen and Kumpulainen (2002).***

BARNEY'S INTERVENTIONS		EXAMPLES
Concluding moves	Refers back to the opening question	*Opening: Ba.-* ***Why are there more birds that eat our vegetables during the winter?*** (…) Closing: Ba.- ***That's why this is the worst time for [having] plagues of birds that eat our leaves****. That's why we have to put plastic bottles to cover our plants, because the birds look for food. Your spines, the well-being of each one of the plants on your spines is an assessable dimension, so that each one here has to manage them so that the bird does not eat his/her plants. And there are people who have plants that birds like a lot, and others who have onions or garlic, bad luck.* (E#1; Y8.O1-Ba)
	Rephrases the last idea and adds some information	*S7.- Because,* ***maybe, on their way from one side to another, it depends on how it is, maybe they get spoiled or something ...*** ***A.- They lose property for sure.*** *We can verify this. When the tomatoes appear here, we're going to ... I do tomato tastings many times. I take the tomato directly from there [pointing to a tomato bush] and I put it in the class. And you will see how the taste changes if it is a product directly taken from the plant or a product that has a certain time. The regulations say… I do not know how much for the tomato was, but I think they can be sold even after spending a week in the truck, for example.* ***That makes it lose property, the tomato, for the fact of being ... okay? Because keep in mind that it is a plant, which is connected to the vascular system of the plant, and that water is reaching it, and a series of nutrients are arriving. At the moment that you pull it up, nothing comes of that. In fact, there comes a time that it rots. That is an argument.*** (E#6; Y8.O8-Ba)
	Rephrases the last intervention to conclude	Ba.- Motivated by…? Those physical changes in women, why do they occur? For an increase in sex hormones, in this case. And what's the final sense of it? **S6.- For the birth canal.** **Ba.- Well, she is being prepared to become a mom**. (E#7; Y10.O1-Ba)
	Remarks the objective of the activity	*Ba.- (…) Can anyone give me an explanation for the second descent?* *S3.-The Spanish civil war.* *Ba.- Wars kill people.* ***Notice that the data is telling me part of the history of a country. I can know things about a country by researching only numbers. This is based only on numbers of deaths. Look at the amount of information a single datum can provide*** (E#13; Y10.O4-Ba)
	Does not give a final answer	*Ba.- It might make sense, because we have seen that one of the functions of the frontal lobe, which is the one that takes longer to develop... do you remember what its function is?* *S4. Planning and problem solving.* *Ba.- This is very important, because at your age the problems are the biggest in the universe, and then you realise that they are not so big. And that could be related to the way in which one faces the problems that arise in one's life. At your age it is not fully developed to undertake this...* ***it makes sense, although I do not know if it is related to this.*** (E#10; Y10.O4-Ba)

The communicative acts analysed appeared within dialogues between Barney and the students. These dialogues have well-defined patterns of interaction, like the IRF sequence (Table A.9.4.d). Barney usually frames some questions to the students, responds with a comment and pushes them to continue the reasoning through a certain direction. There are few occasions in which the sequence *Barney-Student1-Barney-Student1(2)-Barney-Student1(2)(3)-Barney-...* is broken. In some cases, several students answer before Barney utters his evaluation (e.g., E#1-Ba), while in others, a student contributes with an idea without having been directly asked by Barney (E#6-Ba).

Table A.9.4.d) Patterns of interaction present in Barney's episodes on explanation

PATTERNS OF INTERACTION	EXAMPLES
Student interventions sequences	*Ba.- Why are there more birds that eat our vegetables during the winter?* ***S1.- Because they feel attracted by the smell of the plants.*** ***S2.- Because they want to take the pollen from the plants.*** *Ba.- But, is it now the time for pollen production?* *S2.- No, well..., I don't know.* *Ba.- Do we currently have any plague in our vegetable garden?* ***S3.- No... yes, birds!*** ***S4.- Ants...*** (E#1; Y8.O1-Ba)
Student's intervention without being interrogated	*Ba.- The tomato, for example, okay? The tomato, naturally, does not..., if we sow tomato now, if we sow it here, and will not come out on a natural way. You must provide it a series of conditions so that it comes out. However, supermarkets are full of tomatoes. And not just tomato. Like tomatoes, we could say many others.* ***S4.- There are different climates around the world.*** (E#6; Y8.O8-Ba)
IRF sequences	*Ba.- Why is there not a match between the data we find in nature and the numerical ideal we already know? **What factors alter that ideal number?** There are many possible.* *S2.- The sample could get broken. There are rice grains that were ...* ***Ba.- This happens in real life. For sure, some of Mendel's peas were overripe. What else? Why these are not the ideal proportions?*** ***S3.- Because there are mutations.*** ***Ba.- Because there are mutations, we already know that there are**. Or, maybe, it comes a bird who likes more white grains than yellow ones and eats them, I do not know. There are a lot of variables in nature that occur. **What is done in science to counteract all these variables?*** *S4.- Do it many times.* *Ba.- Do it many times. The more times, the more volume of data I have, the more I will approach the ideal proportions. Here we have a small sample, but Mendel made thousands and thousands and thousands of crossbreeding. He spent his life counting*. (E#16; Y11.O5-Ba)

A.9.5. Barney's Knowledge of Assessment (KAs)

Something Barney's profile showed (§A.9.1) is that, for him, assessment plays a fundamental role in the learning process. In that section, I commented about the diversity of assessment tools Barney deployed to assess a vast plurality of dimensions. Barney himself acknowledged in his interview that, in line with those learning objectives that go beyond the acquisition of subject-matter content, he considers many evaluable factors:

> *"I assess the results of theoretical and practical exams, but also their teamwork and their oral presentations (…), the general attitude in the classroom and the attitude towards themselves and their peers, something that will greatly influence their future. We also evaluate the general state of the materials and the care they take of them (how they have their notebooks, the tidiness, the presentation), their creativity and, finally, their capacity for self-improvement"* (I-Ba).

In one after-class informal conversation, Barney showed me the Idoceo® profiles he had created for his students. I could check *in situ* the assortment of marks (numbers, letters, symbols and comments) he had for each of them. In this program, each column corresponds to an activity or task; the teacher can assign the column a specific weight for the overall score. Idoceo® also allows teachers to design rubrics for assessing students' in real-time; with a single click, that information is transferred to the Idoceo® profile of the corresponding student. For example, one of the columns for Year 7 remitted to the rubric Barney had designed for students' oral presentations on their investigations about worldwide plants. The rubric was utilised to assess the quality of the slides, as well as student's expository clarity, their use of language, and their ability to answer the questions posed by Barney during the presentation. Both episodes number 5 (E#5-Ba) and 6 (E#6-Ba) took place within the frame of these presentations. Similarly, for Year 11 students, there was a column for the evaluation of the activity on Mendel's laws. One section of the rubric linked to this column/task referred to students' presentation of conclusions, which did include some scientific explanations. It can be said, then, that students' ability to compose an explanation is formally assessed, although tangentially. Another episode that illustrates Barney's Knowledge of Assessment of scientific explanations is Episode 4. As outlined in section A.9.3, this episode is part of a POE sequence, albeit incomplete. When Barney tells the student that he expects her to explain why the chosen variables influence (or not) her plants' growth, Barney is leading her to believe that this is indeed one dimension he will assess (E#4-Ba).

Barney, then, does assess some aspects related to the construction of explanations. However, although he recognises it is very important that students know how to elaborate scientific explanations, he does not seem to possess any formal model to assess either the process of constructing the explanation nor the product. When interviewed about the possibility of assessing students' engagement in this epistemic practice, Barney said that although he would like to, he doesn't have enough time for it.

In addition to the rubrics that include aspects related to students' ability to explain (in the sense assigned by Barney), there are numerous examples of informal assessment during the episodes analysed. Questioning, observations, and comments are used by Barney to gauge students understanding and progress.

A.9.6. Barney's PCK of Scientific Explanation. Summary and discussion

Generous in his responses, Barney always has something positive to say about education, about Biology, his place of work and his students. This attitude and understanding of science education permeate his teaching practice. His efforts to try to connect with his students so that they can value and love science as he does is worthy of mention.

In Barney, we find a curious mixture of ingenuity about some aspects of science and very deep knowledge of the institutional framework in which science develops. On one side of the continuum, we place his consideration of the scientific method –"*Scientists have developed the scientific method to understand what happens in the world*" (I-Ba). Barney is not alone in this; contradicting what philosophers of science advocates, the belief in the existence of a general, easily described scientific method is quite extended among teachers at different levels of education (Aikenhead, 1987; Osborne *et al.,* 2003). Such a belief may have a noticeable influence on classroom practice, as studies by Brickhouse and collaborators (Brickhouse & Bodner, 1992; Brickhouse, 1989, 1990) show. In the case of Barney, the defence of the scientific method is reflected in the type of activities set forth, in which the students must propose hypotheses, carry out experiments and report their results.

> *"Always, the end of the scientific method is that they share verbally, that they tell everyone, what they have been doing. Of course, with the general scientific format of hypothesis, method and conclusions, and share it with the rest (of the class)"* (I-Ba).

But Barney complements this simplified scheme with a broader view of what scientists do. This is where language and communication come into play; and, with this, the social dimension of the scientific enterprise. To this we must add that, for Barney, not only the construction of scientific knowledge by a community of experts has a strong social character but also the construction of knowledge in the classroom by the students. Collaborative inquiry and cooperative work, group discussions, peer learning and an interactive approach, are a constant in their practice. This social perspective on knowledge creation and acquisition may be key to grasp what role the construction of explanations may play in Barney's classes.

As an epistemic practice with its own norms and language, learning to explain requires students to be introduced to a specific kind of discourse. By this engagement, students are socialised into a particular community of knowledge; this process has been qualified as a cultural apprenticeship (Matusov, Bell & Rogoff, 1994; Brown, Collins & Duguid, 2005). According to Morine-Dershimer and Kent (2006), the creation of learning communities that share forms of discourse and promote certain types of communication patterns may help students develop their reasoning and thinking skills. In their model of science classrooms, Mortimer and Scott (2003) incorporated the socio-cultural conceptions on science and learning. Under this model, Barney can be said to have a dialogic orientation towards teaching science. This means that he provides many opportunities for students to engage in whole-class discussions and student-teacher interactions to create new knowledge.

At the same time, Barney supports students in internalising and making individual sense of the knowledge the community has created. In this process of creation and internalisation of knowledge, Barney defends the importance of students being able to communicate their ideas freely –"*they have to communicate, since we are social. And our future depends a lot on how we communicate with the rest*" (I-Ba). Barney's thought are in line with Schwarz's (2009), who proposes that science teaching should be oriented towards designing dialogic environments in which students are involved not only by recognising their personal points of views and objectives, but also by identifying and understanding objectives and targets of all the participants in the communicative interactions. The role of the teachers in this case includes, among other things, acting as an emissary of the scientific community; that is, she must present the point of view closest to the canonical school science (Scott *et al.*, 2006) and encourage students to consider it, without necessarily meaning that his perspective is the one that should always be imposed. In the episodes that I have categorised as Interactive/Dialogic, we can appreciate this opening towards different perspectives.

How the teacher communicates and interacts in these discursive exchanges has a very high impact on the way in which students themselves interact with their classmates and with their own learning (Gillies & Khan, 2009; McNeill & Pimentel, 2010; Nussbaum & Edwards, 2011;

Ryu & Sandoval, 2012). Gillies and Khan (2009) designed an intervention with middle-school Mathematics teachers to study the influence of their questioning techniques on students' reasoning skills and ability to collaborate in groupwork. They found that the students whose teachers had been trained to challenge students with high-order questions were better in posing questions and providing justifications themselves, compared to the students whose teachers did not received this explicit training. I do not know whether Barney has received any type of specific training to encourage reasoning and cognitive effort in his students. But I can assure that in his practice, we can find countless examples in which Barney challenges the students while being immersed in epistemic tasks. The quality of the questions asked by their students and their ability to reflect and reason account for Barney's ability to create the optimal conditions for this to happen. In this environment, the construction of explanations (something that requires ability to connect and integrate different pieces of knowledge) can be introduced in such a way that students will know how to respond to the challenge. Gillies and Khan (2009) establish that "learning to seek and provide high-level explanatory responses is an important part of learning to dialogue together" (p.9). Thus, there is a positive feedback between the development of the capacity to build explanations and the ability to dialogue. The episodes found in Barney seem to delve into this reciprocity, albeit not explicitly.

BARNEY			
Orientation Toward Science (OTS)			
Knowledge/beliefs about the goals of science	Knowledge/beliefs about science teaching and learning	Teaching practice	Knowledge/beliefs about Scientific explanation
· Science as a method to understand the whole universe · Recognition of epistemic aspects of science	· Recognised objectives: 1) Awaken students' particular interest; 2) Cover the (selected) curriculum · Importance of emotional aspects of learning · Active engagement	· Lessons plan: based on students' interests · Content: purposively selected · Practice: cooperative learning · Context: Dialogic environment · Incorporation of new technologies · Opportunities to engage in authentic disciplinary practices	· Assortment of meanings for the verb 'explain' (Explanations, Sense-making and Justifications) · The practice is not explicitly taught · Valued practice
Knowledge of Instructional Strategies (KIS)			
Communicative approaches	Activities	Language devices	Interaction patterns
· Interactive/Dialogic (8) ·Interactive/ Authoritative (7)	· Whole-class dialogue · Teacher-Student dialogue	· Questions · Requests/Invitations · Repetitions · References · Summaries · Misconception notice	· Student interventions sequences · IRF sequences · Student's spontaneous intervention
Knowledge of Assessment (KAs)			
Dimensions to Assess		Methods	

· Content acquisition · Students' engagement in practices · Lab work, presentations	· Rubrics (general and tasks-specific) · Peer-assessment and self-assessment · No specific model/ instrument to assess students' explanations · Informal assessment

Table A.9.6). Summary of Barney's PCK of scientific explanation

A.9.7. Explanation-building episodes in Barney's case.

EPISODE 1 (E#1; Y8.O1-Ba).

*Ba.- **Why are there more birds that eat our vegetables during the winter?***

S1.- Because they feel attracted by the smell of the plants.

S2.- Because they want to take the pollen from the plants.

Ba.- But, is it now the time for pollen production?

S2.- No, well…, I don't know.

Ba.- Do we currently have any plague in our vegetable garden?

S3.- No... yes, birds!

S4.- Ants...

Ba.- Have the ants caused any harm to your plants? From now on, it is forbidden to kill. The main plague we currently have are the birds. I am going to ask some individual questions, ok? For example, Anne, what do birds eat? Think on a little bird.

S5.- Bird seeds, leaves, ehm.., worms, seeds, ehm…, insects. They eat everything!

Ba.- In which time of the year are there more insects, Albert?

S6.- During the spring.

*Ba**.- Why? There are two reasons**.*

S6. Because it is when the plants open.

Ba.- Ok, plants do bloom in springtime, very good. And many insects eat flowers and eat pollen and nectar. But there is another reason…, Andres?

S7. Because the eggs hatch?

Ba.- The eggs hatch… the reproductive cycle of insects is organised in such a way that… why do they have it organised like that?

S8.- For not to die when it's cold.

[Laughs]

Ba.- We have already studied this. Remember that there are both cold-blooded and warm-blooded animals. (…) Are insects cold-blooded or warm-blooded? Well, I mean, they do not have blood…, do they regulate their temperature, or not? Do you regulate it? Yes, you do keep it at approximately 36-36.5ºC, regardless of the outside temperature. Can an insect do that?

S8.- Yes.

Ba.- Which what percentage of confidence?

S8-. 0%

Ad.– Oh, wow! let's see…, Angel?

S9.- They do not regulate it. I'm 50% sure.

Ba.- What does an insect have to do to regulate its temperature?

S9.- Get in motion. Stay in the sun.

*Ba.- Most insects possess little wings that move… I don't know if you have noticed, but in the springtime, or in the summer, there are much less insects in a cloudy day than in a sunny day. **Why, Amanda?***

S10.- Because as they do not regulate their temperature, they have to be warm for…

Ba.- The little wings need heat to be able to move, and that heat is taken from the sun. That's why in cloudy and cold days there are not so many insects in the field, even being spring or summer. So, is it insects time now?

Ss.- No!

Ba.- So, the little bird that eats insects and notices that there are no insects now… what can it do?

Ss.- It eats our plants!

Ba.- That's why this is the worst time for [having] plagues of birds that eat our leaves. That's why we have to put plastic bottles to cover our plants, because the birds look for food. Your spines, the well-being of each one of the plants on your spines is an assessable dimension, so that each one here has to manage them so that the bird does not eat his/her plants. And there are people who have plants that birds like a lot, and others who have onions or garlic, bad luck.

EPISODE 2 (E#2; Y8.O1-Ba).

Ba.- What do we have to do before the sowing?

S1.- We have to stir the soil.

Ba.- ***Why do we have to do that?***

S2. For it to aerate.

S3. For it to oxygenate.

Ba.- ***For it to oxygenate, why?***

S4.- For plants to have enough nutrient.

Ba.- But why do we have to oxygenate the soil? Through where do the plants take most of the material that will build them and make them grow from the little seed they were?

S5.- Through the root…, from the air, from the carbon dioxide…

Ba.- That's a very extended misconception, isn't it? "Plants are fed by the roots"; no. The plant…, most of the carbon that is used as building material for the plant comes from the CO_2 that is around here. What does it take from the root?

Ss.- Nutrients.

Ba.- Minerals and nutrients, but not most of the material that constitutes it, right?

EPISODE 3 (E#3; Y8.O1-Ba).

S1.- ***Why do the snails go out when it rains?***

S2.- Because they are sluggish and crawl through the water.

Ba.- Well I do not know exactly; I should think about it.

EPISODE 4 (E#4; Y8.O3-Ba).

S1.- Barney, if you know of an element to add to your plant…, ahm…, that will help it growth because it's good…?

Ba.- What are you thinking about?

S1.- In the milk.

Ba.-I know the plants do not need milk but, hey, if you want to pour milk every Thursday, it seems good. I do not know what will happen, but what is your hypothesis? What do you think will happen?

S1.- I think it's going to be fine, because my mother uses it in my house.

Ba.- And what happens?

S1.- Well, when the leaves become faded and they fall, then they grow back.

Ba.- ***Why?***

S1.- I don't know.

Ba.- Well, that's what I want you to know. But that will come later.

EPISODE 5 (E#5; Y8.O6-Ba).

Ba.- You have mentioned the whole wheat there; do you know what it is? What is the difference between whole wheat and non-whole or refined wheat?

S1.- The whole is healthier.

Ba.- Yes, but the difference in the grain. ***If you know why one is called 'whole' and the other is not.***

S1.- Well, the whole is like brownish.

Ba.- ***Okay, yes, do you know why?*** *What has the whole wheat that the other does not have? Or rather, what does not have the other, the refined one...? Who knows?*

S2.- I do not know, but I think that the refined one has this sort of peel…

Ba.- There is a layer (...). If you take the grain of wheat, it has a first layer, and in the refining process, it is removed, right? That first layer is fibre, fundamentally. That is why it is said that the whole is very good for the digestive tract. The fibre, what it does in the intestine, in the intestines, is that it facilitates the passage of food through the intestines, so that it regulates very well everything that has to do with the peristaltic movements that lead the food through the tube. This is very good, okay? Most of the food we eat that come from cereals come from refined grains that have had this first layer removed, right? Now at least we know…, because we always heard people say: "the integral is better", but we did not know why. Now you know that it is because it has fibre, and fibre is very good. Today, wholemeal food is in fashion, but a few years ago it was not so common. The first layer was removed from everything. Today, as it has been seen that it is beneficial for... besides, a good thing that fibre has is that it gives you a feeling of satiety, and you eat less when you eat something whole. Fibre…, we do not have bacteria, nor digestive enzymes to digest fibre. So, fibre is something that runs through the digestive tract and finally we expel it with our faeces, okay? However, the feeling of being full is because it occupies a space.

EPISODE 6 (E#6; Y8.O8-Ba).

Ba.- I would like to invite you to reflect. You said that [lettuce] can be seeded practically at any time. We're going to take advantage of the fact that he has commented on that to ... uh, in fact, we do it here, don't we? We seed it at any time. We have this planted and it is growing well, the lettuce. ***Why do you consider it important that you can seed lettuces at any time?***

S1.- So that we have more lettuce.

[Laughs].

Ba.- I think the question is not well posed, but well, I can reformulate it. Alba?

S2.- It is good that it can be planted at any time because the lettuce is eaten, well, at least in my house, it is eaten throughout the year.

Ba.- Well, if you want to eat a product during the whole year, it is interesting that the product can be grown all year. Do you know any product that is not grown, or does not grow equally, throughout the year, for example, here, if we talk about our country?

S3.- The tomato.

Ba.- The tomato, for example, okay? The tomato, naturally, does not..., if we sow tomato now, if we sow it here, and will not come out on a natural way. You must provide it a series of conditions so that it comes out. However, supermarkets are full of tomatoes. And not just tomato. Like tomatoes, we could say many others.

S4.- There are different climates around the world.

Ba.- And what does that originate?

S4.- That there may be tomato at all times of the year.

Ba.- And now, if we talk about responsible consumption, what information should we have so that our way of consuming food is the least harmful to the land or to the environment? How does that affect, Arantxa?

S5.- We should know when the season of each thing is. Because many times they are not planted in other countries, but they change their DNA, or with chemical products to help [the plants] grow, but it's always going to be better to eat them from your garden.

Ba.- In other words, you say that there are two ways [for the products] to reach the supermarket despite not being their time: one, altering them genetically, that is true. In Spain there is not much of that now, but well, there is a debate. And another way is by importing them. What are the consequences of both? Why is it better to consume what has been locally ...?

S6.- Because your country is going to earn more.

Ba.- OK, that's an argument: I want to boost the economy of my country, and I buy products from my country. It's not where I was trying to go, but ...

S7.- Because, maybe, on their way from one side to another, it depends on how it is, maybe they get spoiled or something ...

Ba.- They lose property for sure. We can verify this. When the tomatoes appear here, we're going to ... I do tomato tastings many times. I take the tomato directly from there [FN_EIA: pointing to a tomato bush] and I put it in the class. And you will see how the taste changes if it is a product directly taken from the plant or a product that has a certain time. The regulations say… I do not know how much for the tomato was, but I think they can be sold even after spending a week in the truck, for example. That makes it lose property, the tomato, for the fact of being ... okay? Because keep in mind that it is a plant, which is connected to the vascular system of the plant, and that water is reaching it, and a series of nutrients are arriving. At the moment that you pull it up, nothing comes of that. In fact, there comes a time that it rots. That is an argument.

EPISODE 7 (E#7; Y10.O1-Ba).

*Ba.- **Why does, suddenly, some physical changes occur on your body that had not occurred before? Why?***

S1.- Because the level of hormones increases.

*Ba.- **And why does the level of hormones increase at a certain time of your development?***

S2.- Because that prepares you to become a mother or a father.

Ba.- Ok, that's the evolutionary sense, but why does that change happen suddenly? What happens in the body that causes that level of hormones to increase? Who does produce the hormones? Where are they produced?

S3.- in the brain.

Ba.- Not only in the brain, but also in the gonads. But their release depends on two other hormones that have been previously released in the brain. We spoke about two especially, although there are many more: dopamine and oxytocin. Dopamine has many effects on the body.

S4.-One is that the reward is greater than the risk, you value it more.

Ba-. It activates more reward circuits in the brain ... and what consequences does it have on a teenager's brain?

S3.- That they risk more than an adult and do not think about the consequences.

Ba.- Can you give me an example of real life? This also happens in adults, especially boys, who like to show off to others. We do not stop being instinctive animals. And this is closely related to the increase in dopamine levels. What about the Oxytocin?

S5.- One of the things related is that you leave your family a little aside and you are more with your friends, you give more importance to your peers, to people of your age.

Ba.- What evolutionary sense does that have?

S5.- The reproduction.

Ba.- Expound on it a bit more.

S5.- Well, by spending more time with your peers, you can end up with a girl and breeding.

Ba.- Notice that this behaviour is motivated by the production of certain hormones. I told you that all these changes, in the end, have the evolutionary sense of reproduction; to find a partner and perpetuate the species.

S6.- In women, breasts and hips increase.

Ba.- Motivated by…? Those physical changes in women, why do they occur? For an increase in sex hormones, in this case. And what's the final sense of it?

S6.- For the birth canal.

Ba.- Well, she is being prepared to become a mom.

EPISODE 8 (E#8; Y10.O3-Ba).

Ba.- What has caught your attention in this document?

S1.- The increase in the number of deaths with respect to the previous year. It is weird that there is so much variation from one year to the next, both in boys and girls.

Ba.- ***How would you explain that?*** *I'm always going to ask you why you think that data are like that. This is a tendency that always occurs ... what do you think can be attributed to the fact that there are more deaths each year?*

S1.- To drugs.

Ba.-To drugs? Do you think that there are more drugs year by year?

S1.-No, but every year [people] hook on earlier.

S2.- Or because every year there are more drunkards that take the car ...

Ba.- But are there more and more drunkards? That is not… what re you based on? On the contrary, the government proposes progressively more measures, and we are progressively more aware of many things that happen... then, why is there this increase?

S3.-Well, maybe because of a big fire ... in a fire people can die ...

Ba.- Is there a super fire every year? (…)

S3.-No, but, that is ...

S4.- More people die every year because there are more and more people.

Ba.-That's it! There are more and more people in Spain, that's why more and more people die every time. In fact, we are in a stage of exponential growth of the human population. Do you know how many inhabitants there are on the planet, more or less? Between 7,000 and 8,000 million, very well.

EPISODE 9 (E#9; Y10.O3-Ba).

Ba.- why do you think that the number of deaths due to congenital malformations decrease so dramatically after 20 years-old? *S1.- Because our organs and limbs or systems are already well developed and cannot be modified.* *Ba.- That's not true ... they are better developed but it does not mean you cannot...* *S2.- Because they do not reach that age.* *Ba.- They have all died before. Most do not reach that age. In fact, if you see the graph you see that in the first year almost everyone dies, then, they die gradually, until they reach the age of 20, in which they have practically all died.*

EPISODE 10 (E#10; Y10.O4-Ba).

S1. From the age of 30, as [people] get older, there are fewer deaths due to external causes. ***Ba.- Why? Now I'm going to ask for your opinion. Why most people who die due to external causes are in that age group?*** *S1.- because at that age they take more risks.* *Ba.- Can we relate that to something we have learned about the brain? With what?* *S2.- With oxytocin. More teenagers die because they take more risks because oxytocin levels in their brain increase and one of the effects is that ... [they] value the reward more than the risk.* *Ba.- I do not know if that is the explanation, but it could be one of the possible ones. Can anyone think of another explanation for the fact that at that age there are many deaths due to external causes?* *S3.- For example, with regard to suicide, as in adolescence you are more affected by the comments of people of your same age, maybe what they say affects you in another way, in an exaggerated way, and that takes you to suicide.* *Ba.- It might make sense, because we have seen that one of the functions of the frontal lobe, which is the one that takes longer to develop... do you remember what its function is?* *S4. Planning and problem solving.* *Ba.- This is very important, because at your age the problems are the biggest in the universe, and then you realise that they are not so big. And that could be related to the way in which one faces the problems that arise in one's life. At your age it is not fully developed to undertake this... it makes sense, although I do not know if it is related to this.* *S6.- Respecting what we have talked about deaths from external causes in people of our age and a little older, I think another reason is that as at our age there are many fewer cases of diseases, tumours, or diseases of the heart, and therefore, the percentage [of deaths due to] of external causes is higher.*

EPISODE 11 (E#11; Y10.O4-Ba).

Ba.- ***Why do more people in Asturias die from diseases related to the circulatory system?*** *S5.- For their life habits.* *Ba.- What, for example?* *S5.- They eat a lot of pork. Chorizo, morcilla ..., things with a lot of fat.* *Ba.- And why at your age is there less incidence of these diseases?*

S5.- Because when we are younger we have the body better protected, our defensive system is stronger.

Ba.- Hmm, more than what you have because of your youth, it's because of what you do not have. Throughout your life you accumulate bad habits, and those bad habits do have consequences. At your age, you may have accumulated bad habits, but very few…, or fewer than older people. Apart from that, your metabolism changes after 20 years, as well as your lifestyle. Because now you are very dynamic, very active, but you will see how that changes.

EPISODE 12 (E#12; Y10.O4-Ba).

Ba.- Bianca is very interested, and so am I, in talking about life expectancy (in fact, this is what I was going to talk about now and compare it between different countries). What do you want to comment on, Bianca? (…) ***Why do you think life expectancy is those countries are those?***

S1.- Well, from my point of view, and from what I have researched, these differences are due to the food of each country and the diets people follow. Because, for example, the Internet shows that the diet of the Japanese is very good.

Ba.- One of the factors that makes it so is the type of food. Something that one can modify at will. This is very important.

S1.- The conflicts that exist or have existed in that country, such as in Sierra Leone, has also a strong influence.

A.- Ok, the general state of the country. We, fortunately…, when you go to other parts of the world, you realize that in Spain there is one thing that we do not value, that is peace and stability. Here you can walk down a street relatively confident. In other countries, you do not live like that. They live in a state of alert and stress such that it ends up affecting their lives. Here we have some policies for security, peace and welfare rather high. In fact, there are many people who travel the world and decide to settle in Spain because it is one of the countries that is more balanced between many factors. What happens is that we, who are inside, find it hard to value it because we always aspire to the best. And we are more critical. But in Spain you can live well, in general.

S1.- And, of course, the health system of each country, since, if there is any disease, you must have the medication or the treatment to cure it.

Ba.- Totally true. The health system has a great effect on death rates. And fortunately, in Spain we also have a good health system, always improvable, and above all that, until now, it has been public, which is something that we also hardly value, but when you go to other places you realise how important it is to have a public health system that takes care of anyone when something happens.

EPISODE 13 (E#13; Y10.O4-Ba).

Ba.- I want you to do it on your screens, and I'm going to ask you two very important questions; all of you, look at here. You see that here, suddenly and beastly, because it is brutal, around 1918 life expectancy dropped a lot. I want you to tell me what happened. And here there is another great downhill. I want you to tell me now why. You have to research about this on the fly. Do not make it up; I want you to investigate and tell me.

Who has something? ***Who knows how to explain this little dot here?***

S1.- The First World War.

Ba.- No.

S2.- It was an epidemic. The 1918 influenza pandemic. (…). ***Can anyone give me an explanation for the second descent?***

S3.-The Spanish civil war.

Ba.- Wars kill people. Notice that the data is telling me part of the history of a country. I can know things about a country by researching only numbers. This is based only on numbers of deaths. Look at the amount of information a single datum can provide.

EPISODE 14 (E#14; Y10.O6-Ba).

Ba.- If we relate it to everything we have seen about the development of the brain and the hormones, ***do you find any sense that in boys between 15 and 19 years the first cause of death is traffic accidents, and in girls, the first cause of death is suicide?***

S1.- In boys, because of the hormone that makes them see the reward more than the risk… Then, maybe they go fast because of having that adrenaline, or something, and they take the risk and they do not know ...

Ba.- That is. It should be studied scientifically, but surely there is a correlation between the level of hormones, that hormone that exposes you more to the challenges, and the number of traffic accidents. Because in other age bands it does not happen. It coincides with the age range in which the levels of that hormone are higher. We also saw that brain development does not end until 24-25 years. (...) And how do you relate that the first cause of death in girls aged 15 to 19 is suicide? Do you think that this may be related to the hormones we saw, or to the development of the brain, for example?

S2.- Well, maybe with the hormone that makes you have feelings more..., that is, that things affect you more.

Ba.- Ehm, I do not remember that any of the hormones we studied had ..., I mean, it is true that in the cycle - the menstrual cycle, but this lasts the whole life, it does not correspond to a single age range - the levels of hormones in a certain moment of the cycle makes some women more sensitive. But this does not happen at any specific age range.

S3.- I think it's because of the brain. Because something bad happens to you and you do not know how to solve it.

Ba.- Well, we had seen that the frontal lobe of the brain, you remember, where the complex functions are - and one of them was problem solving - is not fully developed at these ages. We are assuming, this should be studied well, but surely it has some relation the fact that they do not have a sufficiently developed brain to give solution to what you think are big problems of your life, and that, if you add to another series of factors, we are seeing that it can lead to suicide, as the first cause of death in this age group.

S2.- Another assumption is that, as in this age group, it affects you more ..., that is, how was all that about the social pressure? So, if you receive negative comments, they can affect you more…

A.- It could be linked to all that. Very well!

EPISODE 15 (E#15; Y11.O4-Ba).

We already know, because we know genetics, that ***this has a genetic explanation****. You know today more than Mendel. Mendel spent his life studying this, because today you come to the school, and you already know more than him. Tell me the genetic basis of that law.*

EPISODE 16 (E#16; Y11.O5-Ba).

Ba.- ***Why does this datum -73%- come out? Does it correspond to what you know?***

S1.- Well, not exactly.

Ba.- ***Not exactly, why?***

S1.- Because we do not have a very large sample.

Ba.- ***Why is there not a match between the data we find in nature and the numerical ideal we already know?*** *What factors alter that ideal number? There are many possible.*

S2.- The sample could get broken. There are rice grains that were ...

A.- This happens in real life. For sure, some of Mendel's peas were overripe. What else? ***Why these are not the ideal proportions****?*

S3.- Because there are mutations.

Ba.- Because there are mutations, we already know that there are. Or, maybe, it comes a bird who likes more white grains than yellow ones and eats them, I do not know. There are a lot of variables in nature that occur. What is done in science to counteract all these variables?

S4.- Do it many times.

Ba.- Do it many times. The more times, the more volume of data I have, the more I will approach the ideal proportions. Here we have a small sample, but Mendel made thousands and thousands and thousands of crossbreeding. He spent his life counting.

A. 10. ETHICAL DIMENSIONS OF MY RESEARCH

When carrying out a research project, some kind of intervention in the lives of other people is inevitable (Schostak, 2002), something that could have consequences that are worth stopping to reflect on. For example, as part of the process of finding answers to my research questions, I engaged in fieldwork in four different schools, which means that I had to be in daily contact with teachers and young students. As it happens in other fields, in conducting empirical research in education there is a series of ethical measures designed to protect the participants, minimising any negative impact that such intervention may have on them. The major measures involve: 1) voluntary and informed consent; 2) harm avoidance; and 3) respect for anonymity and privacy (Fouka and Mantzorou, 2011). These ethical concerns may have real consequences for both the processes of data collection and data analysis, and, therefore, for the results that can be generated from this type of research. In this study, I tried to respect all of them through a variety of means.

1) Before starting with my fieldwork, I met with the headmaster of two schools (in Madrid and Seville) and with the head of the sciences departments in the two schools in Cambridge, as well as with some of the science teachers. Before that, our contact had been limited to some e-mails in which I had presented them my project in a general way. These face-to-face meetings were conceived as an opportunity for the potential participant to get to know me more in depth, and to know about my work and interests. But my final objective of these informal interviews was to ensure that they had enough information about the nature of my research and the scope of their involvement, to help them arrive at a reasoned judgement about

whether or not they wanted to participate. After the first encounter, all the interviewees agreed to take part in my project.

One of the points with which I committed myself in these meetings was to send a consent form to the participant teachers prior to the stage of data collection. In this document (Appendix A.12), I provided a more detailed description of my research purposes, the means intended for data gathering, some ethical implications and expectations of their participation and my personal contact information. Moreover, teachers were asked to give their consent to be interviewed and audio-recorded, and to the publication of any interesting findings derived from my research.

With the headmasters' permission, I asked the teachers to send this written summary to all the students' parents or legal guardians to complete it, since although my research is focused on teachers, I wanted to observe how they interact with students in their natural environment. Students whose parental consent were not granted would not be recorded, and any reference to them would be removed from the data set. I was aware that this might complicate data gathering procedures and I was prepared to anticipate these occurrences. However, none of the parents refused to allow their children to participate in my study because of safety or welfare concerns.

2) Another of my main concerns was to avoid harm both students and teachers resulting from their involvement in my research. This included to make sure that none of them would be in risk of to experience physical discomfort or psychological distress. Something I kept in mind from the very conception of this project is that I was going to be working with a vulnerable population -adolescents-, even if they were not my main focus of interest. I also was aware that some teachers might feel overwhelmed at the thought of having a stranger carefully observing -and taking notes, and recording- how they work. In an attempt to minimise their anxiety, I informed teachers about what I was going to do during the observations. I had some doubts, though, about the extent to which I should deepen my explanations of what I was inquiring about; because, on one hand, I expected teachers did not include more activities related to scientific explanation just because I was observing. But on the other hand, hiding information could be considered a form of deception and lack of integrity. As can be seen in the appendix A.12 document, participants were informed that I wanted to "examine the relationships between teachers' knowledge about scientific explanation, their beliefs, and classroom practice, by analysing how they design, facilitate and assess lessons that cultivate the construction of

scientific explanations". So, I decided to be completely open and frank about my purposes, with the hope this would not cause participants to react in a way that would contaminate my results.

I believe that the fact of always being friendly and close to the teachers outside the classroom, as well as answering all the questions that they had regarding my research in an honest way, contributed to create a climate of confidence that caused their nerves to fade after a few sessions.

Some participants did feel some anxiety about audio-recorded material being shared with others, who might judge their performance or their opinions. To minimise this risk, I informed the teachers about how the material would be used and handled after the study, and what type of data that would be collected, emphasising that only I and my supervisor (in case he needed to check something) would have access to the material.

Although I thought there were no known risks to participate in my study as my topic was not controversial, before beginning the interviews, teachers were reassured that they were free to refuse answering any question if they feel inclined. Moreover, all the participants were told that they had a right to withdraw at any stage of the research before the results of the analysis would be reported or published (Robson, 2011). This was the case of Annabelle and Álvaro, and therefore all the information collected from them were purged.

I also avoided any harm to myself, taking matters of personal safety seriously and without exposing to unacceptable danger or pressure in the pursuit of data.

3) I guaranteed to all participants that the data gathered would be treated as fully confidential. This means two things: i) that any information or remarks that could be used for the identification of individuals within the data set (including the students and the schools) would be removed from the transcripts and the analysis, and would therefore not be presented in any of the results, nor in my thesis, neither in any related publications. All participants were assigned a pseudonym maintaining the gender, and the schools were denoted with capital letters (from A to D); ii) that sensitive information would be stored safely (Nunan and Di Domenico, 2013), and just a few selected people could access it. In my case, all the data collected was stored on a password protected device.

In general terms, I tried to act professionally and with integrity. This also includes this dissertation, in which I have followed ethical standards regarding issues such as bias recognition and plagiarism (Robson, 2011).

A. 11. INVITATION TO PARTICIPATE IN RESEARCH PROJECT.

Dear Sir/Madam,

Mi name is Elisa Izquierdo-Acebes and I am a second-year PhD Student in the Faculty of Education at the University of Cambridge. I am conducting a study on the role of science teachers in the development of students' explanatory skills. More precisely, I want to examine the relationships between teachers' knowledge about scientific explanation, their beliefs, and classroom practice, by analyzing how they design, facilitate and assess lessons that cultivate the construction of scientific explanations.

I would like to extend an invitation to you to participate in this research project. My idea is to conduct some observations of science teachers in action. During the observations, field notes will be taken to capture some important aspects related to scientific explanation construction, but I am also interested in videotaping the sessions or, at least, in audio recording them. In addition, I would undertake one interview and one group discussion session to delve into the opinions, thoughts and perspectives of the participants on the introduction of scientific practices such as explanations.

Both the observations results and the responses to the questions will be kept confidential. Each interviewee will be assigned a number code to help ensure that personal identifiers are not revealed during the analysis and write up of findings. Only a small number of authorised project personnel will have access to this information for research purposes. Results may be published in Education journals, conference papers, workshops with teachers and my thesis, but it will not be possible to identify you in the results of the study when these are published.

There is no compensation for participating in this study. However, your participation will be a valuable addition to my research and findings could lead to greater understanding of science teaching.

If you think you could be interested, please, let me know by email. You can suggest a day and time that suits you and I'll do my best to be available for a meeting.

If you have any questions, do not hesitate to ask.

Thank you in advance,

Elisa Izquierdo-Acebes.