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TESE DE DOUTORAMENTO

O DESENVOLVEMENTO DAS PRÁCTICAS CIENTÍFICAS DE CONSTRUCIÓN E USO DE MODELOS E PROBAS: UN ESTUDO LONXITUDINAL EN EDUCACIÓN INFANTIL

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DECLARACIÓN DA AUTORA DA TESE

O desenvolvemento das prácticas científicas de construción e uso de modelos e probas: un estudo lonxitudinal en educación infantil

Dna. Sabela Fernández Monteira
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O desenvolvemento das prácticas científicas de construción e uso de modelos e probas: un estudo lonxitudinal en educación infantil

Dna. María Pilar Jiménez Aleixandre

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Índice:

SUMMARY

The objective of this thesis is to analyze the ways in which children engage in scientific practices and how this engagement evolves from first to third year of Early Childhood Education (ECE).

Over the last decade, there is an increasing number of publications (e.g. Osborne, 2014) and curricular documents (National Research Country, NRC, 2012) that consider science as a set of practices of a social nature. Aligned with this view of science, the examination of science learning processes should shift “from viewing science as a set of processes to emphasizing, also, the social interaction and discourse that accompany the building of scientific knowledge in classrooms” (Reiser, Berland & Kenyon, 2012, p. 8). This study is framed in this approach. As a consequence, the research objective is addressed through the examination of *how* children build scientific knowledge in the ECE classroom and how the meanings are built and communicated according to the culture of this community.

Children’s engagement in scientific practices is explored through four overarching research objectives, three of them regarding children’s performances and one regarding the teachers’ strategies:

Objective 1. *To explore the features of ECE children’s engagement in using evidence and what is the role of purposeful observation in this practice.* This objective is addressed through the following research questions:

1) In which ways do children in early childhood use evidence and how is this use reflected in the development of data into evidence? What are the differences in the use of evidence between first and third year of ECE?

2) Which ways of gathering empirical evidence are jointly constructed by children and their teachers during the project? Which is the role of observation in this context and which are its features? What

are the differences in gathering evidence between first and third year of ECE?

3) How do children use evidence to revise their understandings? What are the differences between first and third year of ECE in the revision of understandings under the light of new evidence?

Objective 2. *To explore what features has children's use and construction of models, what is the role of representations in this practice and how it evolves from ECE1-L to ECE3-L.* This issue is examined through three research questions:

1) Which science meanings about snails are constructed and communicated by ECE1-L children in their expressed models and how do they change during the year?

2) Which communicative and representation resources of the science classroom community are appropriated by ECE1-L children?

3) How do children's ways of engagement with scientific expressed models become increasingly more complex from ECE1-L to ECE3-L?

Objective 3. *To explore which are the features of building explanations in ECE3 and how this practice evolves along a school year*. This objective is addressed through the following research question:

What are the features of ECE3-L children's explanations about state changes and how do they evolve along the school year?

Objective 4. *To explore how ECE teachers support children's engagement in scientific practices and how scaffolding changes along the three years of ECE*. This objective is addressed through three research questions:

1) Which are the strategies used by the ECE-L and ECE3-P teachers to support children's engagement in scientific practices?

2) Which are the features and affordances of scaffolding children's engagement with scientific representations?

3) How is the intensity of scaffolding modulated from ECE1-L to ECE3-L?

Theoretical Framework

The study is framed in four bodies of knowledge: 1) socio-cultural perspectives on learning; 2) science learning in early childhood; 3) scientific practices; and 4) social semiotics of visual communication.

Socio-cultural Perspectives on Learning

We understand learning in a dialogic perspective (Bruner, 1966; Vygotsky, 1978) and consider it more as a social than as an individual process. It is mediated by interactions in a given context, in which cultural and social factors influence *what* is learnt and *how* it is learnt. Language plays a central role in cognitive development, as it is the most frequent mean through which information is transmitted from adults to children; it allows communication between peers; and mediates inner thought of a person (Vygotsky, 1991). According to Bruner (1996), learning is a cultural product and the members of a community build meanings through negotiation, mediated by language.

Vygotski (1978) proposes that learning takes place in what he called the *zone of proximal development* (ZPD), which is "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (p. 86). This guidance is known as *scaffolding*, a term which was first introduced by Wood, Bruner and Ross (1976). Scaffolding is progressively withdrawn whilst the person becomes able to carry out tasks autonomously. The three key elements of scaffolding are: contingency, fading and transfer of responsibility (Reigosa & Jiménez-Aleixandre, 2007; Van de Pol et al. 2010). *Contingency* refers to the tailored support of student activities; *fading*, to its progressive disappearance or diminution; and *transfer of responsibility*, to the progressively higher learner's control of the learning situation, cognitively, metacognitively or affectively. Donato (1994) and Moll (1990) use the term "collective scaffolding" to refer to the cooperation between students that allows them to achieve better results than individually.

Science learning in early childhood

According to the OECD (2012) report engaging in science since early ages has affordances in later students' achievement. Although the number of publications with the focus in initial educational levels is growing (Areljung, Ottander & Jue, 2017), there is still less research than about higher educative levels.

According to the literature, children are well disposed to learn science, because they are naturally curious and ask questions about the world around them (Cabe Trundle, 2015; Patrick & Mantzicopoulos, 2015). Fleer and Pramling (2015) suggest the need of helping them in order to support their engagement in science. Metz (2008; 2011) carried out a research program in order to examine if children's engagement in science could be limited by developmental reasons. She concluded that, with appropriate learning environments, children could design investigations of their own and overcome difficulties due to cognitive development.

For 30 years, a line of research known as *Children's Science* (e.g. Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg, 1985) focused on exploring children's and adolescents' *alternative conceptions.* These are considered the pupils' first answers, different from the scientific community, resistant to change and persistent in time.

In the last decade, there is a greater number of publications with the focus on examining *how* students engage in science. Regarding young children, there is interest on examining how they produce scientific knowledge in formal (e.g. Siry, Brendel & Frisch, 2016; Ergazaki, Alexaki, Papadopoulou & Kalpakiorie, 2014) and non-formal settings (e.g. Plummer & Ricketts, 2016) and on developing innovative teaching programs (e.g. *Preschool Pathways to Science* (PrePS), Gelman & Brennemman, 2012) for the first years of elementary and for ECE.

According to Siry (2013), children's interactions when engaged in inquiry can lead to the production of scientific knowledge. Authors such as Andersson and Gullberg (2014) point out the importance of the teacher's strategies in early ages.

In sum, it can be said that children's learning of science benefits from rich learning environments with appropriate teacher's support that allows them to take an active role as learners.

Scientific Practices

Scientific knowledge can be considered as a social construct (Fleer & Pramling, 2015). The social practices through which the scientific community builds knowledge are the *epistemic practices* of science (Kelly, 2008). The terms *epistemic* and *scientific practices* are sometimes used indistinctly. Jiménez-Aleixandre and Crujeiras (2017) suggest that both meanings overlap, especially in the context of the classroom: "we can think of epistemic practices as a broader construct and of scientific practices as epistemic practices in the context of specific learning contexts or content areas" (p.70).

The NRC (2012) framework identifies eight scientific practices:

1) Asking questions and defining problems
2) Developing and using models
3) Planning and carrying out investigations
4) Analyzing and interpreting data
5) Using mathematics and computational thinking
6) Constructing explanations and designing solutions
7) Engaging in argument from evidence
8) Obtaining, evaluating and communicating information

The notion of *competence* is the backbone of the Spanish curricula (MEC, 2006; MECD, 2013). This may be understood as the capacity to apply knowledge to new contexts (Jiménez Aleixandre, 2010). According to the Programme for International Student Assessment (PISA) (OECD, 2016) framework, scientific competence is structured in three main sub-competences: 1) providing explanatory accounts of natural phenomena; 2) understanding of scientific inquiry; and 3) evaluating data and evidence. As indicated by Jiménez-Aleixandre and Crujeiras (2017), the three broad dimensions of practices proposed by NRC (2012) *evaluate and design scientific inquiry*, *interpret data and* *evidence scientifically*, e *explain phenomena scientifically*, correspond to these three sub-competences.

This study focuses on the practices of: a) engaging in argument from evidence; b) developing and using models; and c) constructing explanations. We also focus on the practice of observation, that, although is not identified as a separated practice in the above referred frameworks, it is part of others such as *planning and carrying out investigations* (Duschl & Bybee, 2014).

Engaging in argument from evidence: Argumentation may be defined as the connection between claims and data through justification and the evaluation of alternative knowledge claims (Jiménez-Aleixandre & Erduran, 2008). According to the Evidence Explanation continuum (Duschl, 2008), the construction of evidence based explanations involves three critical transformations: (1) selecting or generating data to become evidence; (2) using evidence to ascertain patterns of evidence and models; and (3) employing patterns and models to propose explanations. Each of these transitions involves making epistemic judgments about “what counts” as data, evidence or explanations.

The literature reports that secondary (Jiménez-Aleixandre, Bugallo & Duschl, 2000) and primary (Songer & Gotwals, 2012) students find difficulties to coordinate claims and evidence through justification. We only found three publications regarding how children younger than 6 years engage in argumentation. Hokayem and Wright (2014) and Plummer and Ricketts (2016) report that, with appropriate learning environments children are able to support claims with evidence. Grube and Maehler (2014) point out that the capacity of evaluating evidence develops during ECE. An article part of this investigation (Monteira & Jiménez-Aleixandre, 2016) contributes to the identification of entry points in the transformation of data into evidence in ECE.

Developing and using models: A model is a representation of a phenomena made with a distinct purpose (Gilbert, Boulter & Elmer, 2000). A model can serve to made visible abstract entities, to describe or simplify phenomena or serve as a basis for predictions and scientific explanations (Gilbert, 2004).

In order to be shared, a *mental model* needs to be transformed into an *expressed model* (Gilbert et al. 2000). Visualization is central to science education, as it allows for moving between the different representational modes in which a model can be expressed (Gilbert, 2004). In our investigation, the most relevant semiotic mode is the *visual* mode, in which a particular type of expressed models, children's drawings, are expressed. Additionally, we examine the *gestural* and the *physical* models built and interpreted by children.

According to the NRC, "Modeling can begin in the earliest grades, with students' models progressing from concrete "pictures" and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades." (2012, p. 58). Despite this recommendation, Louca and Zacharia (2012) report that they found few studies in primary and none in early childhood education regarding how children engage in modeling. Three years later, these authors published another study exploring the differences between 5 and 10 year-olds when modeling. They point to the importance of the teacher's role in supporting modeling in young ages (Louca & Zacharia, 2015). In Plummer and Ricketts' (2016) study, 3 to 6 year-olds were able to build models from secondary data and to use models to generate data.

Danish and Phelps (2011), Fleer and Pramling (2015), and Pérez-Echeverría and Scheuer (2009), use the term *representational practices* to refer to the practices through which students produce (multimodal) representations through which they can access the world. Pérez-Echeverría and Scheuer (2009) indicate that, during this process, mental models and representations interact.

For Gilbert (2004) "a model can include representations both of abstractions and of the material objects on which they act at the same time" (p. 117). Bruner (1996) also addresses in his work the different nature of the representations. According to him, humans represent reality to apprehend it, using three increasingly more complex modes: *enactive*, *iconic* e *symbolic*. Other authors (e.g. DeLoache, 2004) define representation as something that stands for another entity. Peirce (1955) distinguishes between icons, as representations that physically resemble what they stand for, and signs, whose meaning is arbitrary, such as words.

Constructing explanations: A scientific explanation is defined by McNeill (2011, p. 795) as “an account of how or why a phenomenon occurs and explaining why the natural world works in particular ways". Scientific explanations can vary in complexity and, according to Perkins and Grotzer (2005), students are familiar with simple causal models, which are appropriated to explain everyday life, but not to account for scientific phenomena. In order to overcome this difficulty they recommend: “draw their [*students*] attention to how they are modeling the causality involved in particular phenomena and encourage more sophisticated causal modeling” (p. 119).

There are some studies about how primary education students build explanations (e.g. McNeill, 2011; Metz, 2011). Although the affordances of building explanations have been documented (McNeill & Krajcik, 2009; Songer & Gotwals, 2012), students are not often asked to do it (Osborne, 2014; Zangori, Forbes & Biggers, 2013). There is less research about pre-primary levels. It is known that a curricula mediated by children’s interests can support them in building explanations of a certain sophistication (Siry & Max, 2013).

Observation: Observation is addressed by Gelman and Brennemann (2012) as one of the five basic science practices in their program *PrePS*. Observation is an instrument for gathering and interpreting first-hand data (Varelas & Pappas, 2013). In order to be fruitful for building empirical evidence, it needs to be systematic, active and have a purpose (Gelman & Brenneman, 2012). A contribution of this study (Monteira and Jiménez-Aleixandre, 2016), is the characterization of *purposeful observation*, a type of observation prolonged in time, systematic, with a clear focus, explicitly discussed and used to support claims and review ideas.

Social Semiotics of Visual Communication

As expressed by Jewitt and Oyama (2008): “Social semiotics of visual communication involves the description of semiotic resources, what can be said and done with images (and other visual means of communication) and how the things people say and do with images can be interpreted” (2008 p. 134). Children in this study produce drawings in a specific social context, the science classroom, which influences the meanings that are communicated through the drawings and how they are communicated. *Semiotic resources* (Kress & Van Leeuwen, 1996) are means for meaning making. Children choose which ones to use in their drawings, such as the layout of the elements, divisions and connections among them, or their relationship towards the viewer, based on cultural assumptions. Thus, the meaning potential depends on the community where the visual message is produced and received. The meaning potential of semiotic resources in Western cultures can be grouped in three categories: *representational*, *interactive* and *compositional*; and each category includes several types of particular resources (Kress and Van Leeuwen, 1996).

Methodology, Context and Participants

The study is framed in a qualitative approach (Merriam, 2009), and is a longitudinal study. A group was accompanied along the three years of ECE (ECE-L, 23 children, from 3 to 6 years-old), and additional data were collected in another group in the same school, that was accompanied during the third year of ECE (ECE3-P, 25 children, 5-6 years-old), while they were engaged in school science projects about snails (first year of study; ECE1-L and ECE3-P), chicken (second year of study; ECE2-L) and clouds (third year of study; ECE3-L), which lasted for five months each. It is not an intervention study: the design of the projects was entirely the teachers' responsibility. In this thesis, we focus on the first and third year of study, because the science projects allowed children to engage in a variety of scientific practices, whilst on the second year they were mostly engaged in observation.

Data collection involved video-recording the sessions, collecting children's productions, such as drawings, taking field notes and interviewing the ECE-L teacher.

The sessions (35.5 h) were transcribed and discourse analysis (Gee, 2005) was carried out. From the interaction of data with the literature, argumentation (Jiménez-Aleixandre & Erduran, 2008); explanation (McNeill, 2011); and modelling (Schwarz et al., 2009) components were identified in children's discourse, from which rubrics for analysis were developed. From the interaction of data with the literature about scaffolding (Van de Pol, Volman & Beishuizen, 2010), rubrics for analyzing the teacher's verbal scaffolding strategies were constructed.

Children's drawings were subjected to two complementary analysis: content analysis (Bell, 2001), which focuses on *what* is represented; and social semiotic analysis (Kress & Van Leeuwen, 1996), which focuses on *how* the contents are represented.

Results

Children's Engagement in Using Evidence and the Role of Purposeful Observation

a) Our findings point to the distinction between two processes involved in the transformation of raw data into evidence: 1) selecting data appropriate for being transformed into evidence related to a claim; and 2) identifying potential (appropriate) evidence that could confirm or disconfirm a claim. Both need to be scaffolded.

b) Evidence statements have been distributed according to two levels of epistemic judgment. In level 1, statements closer to data; and in level 2, statements involving evaluative judgments meeting one of these criteria: a) identifying patterns in data; b) connecting data and claim through justifications; c) establishing comparison with other data; d) explicitly evaluating one or several alternative claims. Most of the evidence statements both in ECE1-L (75%) and in ECE3-P (64%) belong to level 1.

c) Children used evidence to support their claims and answer questions, with increasing sophistication with educational level: there are less claims supported with evidence in ECE1-L (15.44%) than in ECE3-P (20.6%). There is a higher proportion of evidence statements coded as level 2 in ECE3-P (36%) than in ECE1-L (25%).

d) Children combined first-hand evidence, from experiments or observation, with second-hand evidence from web searches or family knowledge. We define *purposeful observation* as prolonged systematic observation that has a clear focus, is guided by the teacher, recorded, explicitly discussed, and used to test claims and revise initial models.
Most of the evidence statements, 30 out of 57 in ECE3-P and 32 out of 45 in ECE1-L, correspond to the context of purposeful observation.

Children in both groups used evidence from purposeful observation to revise their ideas.

e) In ECE1-L the majority of evidence statements coded as level 2 correspond to purposeful observation (7 over 11), whilst in ECE3-P they are distributed among the three sources of evidence identified in our coding scheme. We suggest that, in ECE1-L there is prevalence of purposeful observation as a source of evidence because it might be an easier practice to engage in. In ECE3-P, experiments provided a frame where the relations between claim and evidence were more explicit and clear-cut from the beginning.

Increasing Complexity in Children's Engagement with Models and Representations

a) The content analysis of two series of drawings of snails from ECE1-L made within a month of difference shows changes in children's models of snails: they became less anthropomorphic and children incorporated new parts of the snail's body, or represented others that were dealt with during the project with more salience or higher accuracy, for instance, the two pairs of tentacles. In the construction of these external representations, children's mental and expressed models interacted, as shown by the rectifications made by children in the process of drawing them.

b) As part of their enculturation in the school science community, children in ECE1-L were exposed to a range of visual communicative resources that they interpreted, appropriated and used in their representations. Through these resources, children communicated the type of modality of their drawings, such as scientific or artistic; connected and disconnected elements in their drawings, indicating the relationships between them; accounted for the relative importance of the elements depicted using semiotic resources as salience, saturation or displacing; and used compositional resources that reveal that they are appropriating written communication and aesthetic awareness.

c) Children in ECE-L engaged in modeling practices in 27 out of the 30 sessions examined. The evolution in children's engagement with models and representations takes place in several dimensions:

- Children became able to engage in a greater variety of modeling practices as they progressed in the ECE years. In ECE1-L children often needed support from the teacher in order to be able to interpret representations. They engaged mainly in using (8 times) and producing (4 times) models. In ECE3-L the proportion between these two types of practices is more balanced: children engaged in using and producing models 17 and 20 times, respectively; and they also engaged once in evaluating models. Gradually, they became more autonomous and did not need so much support from the teacher.

- During the first year, children mostly engaged with visual models, whilst by the third year they engaged with models expressed in visual, gestural and physical modes. The use of a diversity of semiotics modes can be useful to reach children with diverse perspectives.

- In the third year, children engaged in metaknowledge talk about models. For instance, they discussed how the features of a phenomenon were conveyed by a given representation, often spontaneously and they did not need so much teacher's support to engage in this type of talk. Vice versa, they discussed how they could represent the phenomena.

- From ECE1-L to ECE3-L, children became proficient at interpreting and including both iconic and symbolic elements in their representations. In ECE1-L, the teacher introduced all the symbolic and most of the iconic elements. By ECE3-L children were able to decide and draw on their own which ones to include in the majority of their drawings. Iconic elements, such as representations of observable entities, were depicted in greater detail in ECE3-L.

- Children appropriated visual codes that could be used to communicate meanings to others. In ECE1-L, the teacher introduced these codes, such as connecting lines. By ECE3-L children were able to create their own symbolic elements, such as color codes.

Evolution in Constructing Explanations in the Third Year of ECE.

a) Children's explanations about state changes evolved through engagement in the 'Clouds project'. At the beginning they were able to recognize components and phenomena and to express casual relationships with temperature. Eventually, they were able to account for how phenomena took place and explained them making use of scientific vocabulary. They found easier to account for evaporation than for condensation and identified this process in a greater diversity of contexts.

b) Children's explanations emerged from the interaction between everyday and scientific school knowledge and vocabulary. For instance, they related their observations of condensation in the experiments to the presence of mist in the windowpanes and mirrors at bath time. Additionally, they were able to apply the scientific concept of state change from liquid to gas to explain their everyday experiences, such as breathing on plastic on a cold day: "It [*the water from the mouth*] evaporated!."

c) Peer scaffolding benefits explanation construction. Along the course of the project, we find that more ideas that were discussed between peers were agreed and accepted by the group, compared to ideas presented by the teacher. The ideas that had not been "discovered" by them or their peers were more difficult to appropriate, despite the teacher's efforts in explaining the processes involved. For instance, the notion of evaporation as little drops that go to the air, introduced by one of the children, was eventually accepted by most of them. Nevertheless, the teacher struggled to explain to them the notion of condensation as a state change and the effect of temperature and, even though, children were not able to appropriate it.

d) It was easier for children to account for phenomena that were perceptible with senses, as has been studied by other authors. Their explanations about evaporation improved once they were able to observe a bulk of boiling water coming out of a kettle and to touch the condensed water on the mirror placed above it, realizing that it was water. They found difficult to understand the presence of not observable substances in the air. Eventually, they partly accepted that evaporated water "drops" could be in the air even though they were not visible. This understanding seems to be related to the context: they did not apply this notion to consider condensation of water in the air.

Features and Affordances of Teachers Scaffolding of Children's Engagement in Scientific Practices

a) Five interconnected teaching strategies identified as relevant for supporting children's engagement in scientific practices are: 1) recurrence; 2) reflection; 3) supporting science talk; 4) encouraging children's role as knowledge producers and their participation in science; and 5) promoting their autonomy in discourse. These features of the teachers' approach are closely related to the design of the projects, specifically to that they involve learning about a science content along extended time.

b) The ECE-L teacher pursued a series of learning goals that she achieved by combining different scaffolding means:

- The teacher provided children with experiment representation templates, so they could learn the purpose and features of scientific representations, which is a metacognitive goal. These templates contained a title, room for a visual representation and for a conclusion, so that the message could be shared with others and clearly understood.

- She pursued the following cognitive goals: first, learning to write and to read, for which she employed as a mean demanding children to write their names and word labels, or pasting printed words in appropriate order. Second, in order to learn science contents, she demanded children to be accurate in their scientific representations and prompted them to discuss the phenomena before representing it. Third, in order to children became proficient at using both iconic and symbolic elements; she introduced them and designed representation tasks that involved the use of both. Fourth, she pursued children's learning of aesthetic concepts by: intervening in their drawings, in order to make them more aesthetically pleasant, framing templates and asking children to apply an array of decoration techniques. Fifth, in order to support children's learning of different painting techniques she chose different painting tools (e.g. tempera, watercolor) to be used in the drawing tasks.

- She fostered children's interest in the drawing tasks, which is an affective goal, by acknowledging their performances.

According to the analysis of children's drawings, the adjustment of each mean to its learning goal reached the majority of children and had positive effects in their performances and increasing autonomy along time.

c) The intensity of ECE-L teacher scaffolding of drawing tasks along the three years varied in a non-linear way. Nevertheless, for the didactic goal of learning the features of a scientific representation, learning to write and to read, learning aesthetic concepts and learning painting techniques, the intensity of scaffolding decreased. Children took more responsibility as they became increasingly more autonomous: collective scaffolding between peers took more room in detriment of the teacher's scaffolding. Still, in the conditions of low scaffolding, a majority of children were able to meet the teacher's requirements for the task.

Conclusions

The findings of the study allow us to reach the following conclusions:

Regarding the first research objective: 1) We have identified two processes in the development of data into evidence, previous to those reported in studies in primary education (e.g. Songer & Gotwals, 2012; 2013). 2) Complexity in children's use of evidence increases from ECE1 to ECE3. 3) Children gather and generate data from three sources: experimentation, observation and information search. 4) *Purposeful observation* plays an important role in young children's engagement in science, particularly in the generation of first-hand data. 5) Evidence from *purposeful observation* takes more room in the construction of evidence by younger children. 6) Children in ECE are able to use evidence from *purposeful observation* in the revision of their ideas. 7) The main differences between both age groups, ECE1-L and ECE3-P, in the revision of their ideas, are related to the level of detail in the mechanisms proposed and to the use of vocabulary, rather than to children's ability to use evidence to change their models.

Regarding the second research objective: 8) Children express their science understandings through their drawings, which reflect changes in their ideas. 9) Children appropriate communicative resources from the classroom, in addition to science meanings, and these are reflected in their drawings. 10) The complexity of children's engagement in modeling practices increases from ECE1-L to ECE3-L.

Regarding the third research objective: 11) Children in ECE3-L recognize components and processes and propose explanations about state changes. 12) Everyday and scientific school knowledge interact in children's explanations. 13) Peer scaffolding benefits explanation construction. 14) Perception with senses is a key factor in young children's ability to construct explanations about natural phenomena.

Regarding the fourth research objective: 15) Long-term projects and teacher's scaffolding promote children's engagement in scientific practices in progressively more sophisticated ways. 16) The combination of verbal and structural scaffolding means has metacognitive, cognitive and affective affordances in children's production of scientific representations. 17) The progressive decrease along time of the intensity of the teacher scaffolding benefits children's gains and promotes their autonomy and ability to scaffold each other.

Educational implications drawn from the results of the study are: First, the relevance of documenting the development of data into evidence in order to develop instructional programs that support children's engagement in the use of evidence from early ages. For this purpose, it is relevant to identify descriptive statements or raw data, in addition to evidence, claim and justification. This would facilitate the identification of entry points in argumentation learning progressions.

Second, the convenience of integrating *purposeful observation* in ECE classrooms. Purposeful observation supports students in collecting and interpreting data, in the transformation of data into evidence, and in using evidence in order to revise their understandings. Purposeful observation is complementary to investigations and experiments; it poses, perhaps, fewer difficulties for young children. The identification and characterization of *purposeful observation* is a novel and original contribution from this study (Monteira & Jiménez-Aleixandre, 2016), which has been chosen as "Research that matters" from 2016 by a joint NSTA / NARST committee. Difficulties related to the explicit evaluation of evidence from purposeful observation by children, point to the interest of designing instruction in such a way that the generation of data from purposeful observation and its role in building evidence-based claims is framed more explicitly.

Third, instructional design should provide opportunities for children to engage in different types of modeling practices, such as use, production and evaluation of models and representations. Our findings point to the importance of promoting explicit discussion with pupils regarding the purpose and features of representations. Children's ability to visualize would be favored by the inclusion in the classroom of models expressed in a variety of semiotic modes.

Fourth, state changes can be addressed since ECE and set the basis for building more sophisticated explanations. The instructional design should include time for discussing state changes in different contexts with peers, making sense of them and establishing relations, supported by the teacher. Children's capabilities to explain natural phenomena can be supported with the design of experiences that are perceptible with the senses, or, if not possible, providing children with visual or physical models that account for non-observable features of the phenomena.

Fifth, long-term science projects should be included in the ECE classrooms. A narrow focus on a few topics and recurrence along the sessions facilitate learning them in-depth. This recurrence provides continuity through the project. Mere observation does not lead to change, unless there is reflection about data, theoretical claims and their connections.

Sixth, reflection about experiences should be promoted as it helps children's revision of understandings and it is closely related to the notion of purposeful observation. Mere observation does not lead to change, unless there is reflection about data, theoretical claims and their connections.

Seventh, children's ways with science benefit from engaging in science talk about how and why knowledge is built.

Eighth, the teachers' may legitimate children's role as knowledge producers, by encouraging and acknowledging their efforts and contributions.

Ninth, children's age should not be a constraint to promote their engagement in scientific practices in complex ways. Instead, tailored scaffolding along time can facilitate the achievement of sophisticated learning goals.

I. FUNDAMENTACIÓN

1 INTRODUCIÓN

Esta tese ten como obxectivo explorar como participa o alumnado de educación infantil nas prácticas da ciencia e como a súa participación evoluciona do primeiro ao terceiro curso da etapa, que abrangue dos 3 aos 6 anos de idade. En particular, o estudo pretende contribuír a incrementar o *corpus* de coñecemento sobre a participación do alumnado nas prácticas de: a) uso de probas, cun foco na *observación cun propósito*; b) uso e construción de modelos; e c) construción de explicacións, no contexto de proxectos de ciencias de longa duración. De forma complementaria examínase a andamiaxe (*scaffolding*) por parte das mestras. A continuación, abórdanse os antecedentes que dan lugar a este estudo, os obxectivos de investigación e a organización da tese.

1.1 Antecedentes: As Prácticas Científicas

Nos últimos anos, incrementouse o número de publicacións en didáctica das ciencias (e.g. Osborne, 2014) e documentos curriculares (e.g. National Research Council, NRC, 2012) que contemplan a ciencia como un conxunto de prácticas de natureza social nas que a comunidade científica toma parte e mediante as que é construído o coñecemento. Este estudo insírese nesa corrente e, en consecuencia, os obxectivos de investigación oriéntanse á análise de *como* o alumnado constrúe coñecemento científico nun determinado contexto social, a aula de educación infantil e como son construídos e comunicados os significados conforme á cultura desa comunidade.

Segundo Kelly (2008) as prácticas *epistémicas* da ciencia son os modos específicos nos que os membros da comunidade científica producen, avalían e comunican o coñecemento. As *prácticas epistémicas* e as *prácticas científicas* están estreitamente relacionadas entre sí e solápanse, especialmente no contexto da aula: "we can think of epistemic practice as a broader construct and of scientific practices as epistemic practices in the context of specific learning contexts or content areas" (Jiménez Aleixandre & Crujeiras, 2017, p.70).

Esta visión da ciencia demanda que o estudo dos procesos de ensino e aprendizaxe da disciplina contemple un cambio de perspectiva "from viewing science as a set of processes to emphasizing, also, the social interaction and discourse that accompany the building of scientific knowledge in classrooms" (Reiser, Berland & Kenyon, 2012, p. 8).

O marco da avaliación PISA (Programe for Intenational Student Assesment) da Organización para a Cooperación e o Desenvolvemento Económico (OECD, nas súas siglas en inglés), estrutura a avaliación das aprendizaxes en base a adquisición de competencias básicas, que implican a capacidade de poñer en práctica do coñecemento construído en contextos e situacións novas e integran conceptos, destrezas e actitudes (Jiménez Aleixandre, 2010). No marco de PISA (OECD, 2016), a competencia científica está estruturada en tres sub-competencias, interrelacionadas entre sí: 1) construción de explicacións; 2) identificación de cuestións que poden ser respondidas e investigadas pola ciencia; e 3) a interpretación e avaliación de probas para apoiar conclusións. Estas se corresponden prácticas propostas polo National Research Council (NRC) (2012). Jiménez-Aleixandre e Crujeiras (2017) propoñen unha equivalencia entre as tres grandes dimensións das prácticas propostas polo NRC (2012): *evaluate and design scientific inquiry, interpret data and evidence scientifically,* e *explain phenomena scientifically*; e as tres sub-competencias da OECD (2016).

A OECD (2012) indica que a participación en ciencias desde educación infantil ten unha influencia positiva no rendemento do alumnado de 15 anos nesta área. Isto apunta á importancia de fornecer de oportunidades para participar nas prácticas da ciencia ao alumnado de menor idade. A literatura indica que as nenas e os nenos son capaces de participar en ciencia, desenvolvendo pequenas investigacións (Metz, 2008; 2011); e poden xerar coñecemento científico mediante as súas interaccións (Siry, 2014). É importante documentar como participa o alumnado de menor idade nas prácticas científicas, co obxectivo de deseñar ambientes de aprendizaxe que lles permitan desenvolver as súas capacidades. Porén, o número de traballos sobre como nenas e nenos de educación infantil participan nas prácticas científicas é moito menor que sobre niveis educativos superiores.

Esta investigación pretende contribuír a paliar ese déficit, ampliando o *corpus* de coñecemento sobre como fai ciencia o alumnado de niveis iniciais. Nesta tese analízase como participa o alumnado de educación infantil nas prácticas científicas no contexto da aula, como esta participación evoluciona ao longo dos tres anos da etapa de educación infantil, e que tipo de estratexias docentes promoven a participación.

1.2 Obxectivos de Investigación

A tese ten como obxectivo xeral *examinar como o participa alumnado de educación infantil nas prácticas científicas e como evoluciona esta participación ao longo da etapa, de primeiro a terceiro curso de educación infantil*. Para desenvolvelos deseñouse un estudo lonxitudinal, acompañouse un grupo (ECE-L) ao longo de toda a etapa (3 a 6 anos de idade) e tomáronse datos adicionais noutro grupo (ECE3-P) de terceiro curso de educación infantil (5-6 anos). Este alumnado tomaba parte en proxectos de ciencia de varios meses de duración. Non se trata de un estudo de intervención, xa que o obxectivo é coñecer como participa o alumnado de educación infantil nas prácticas científicas nun contexto real de aula. As dúas mestras pertencen a un grupo profesional (*Professional Learning Community*) de seis mestras de educación infantil que, cada ano, levan a cabo un proxecto de ciencias nas súas aulas.

As prácticas examinadas en profundidade son a) o uso de probas e, en relación con el, a observación cun propósito; b) o uso e construción de modelos; e c) a construción de explicacións. Aínda que a observación non está diferenciada como unha práctica no marco das prácticas do NRC (2012), si se inclúe noutras como *deseñar e levar a cabo investigacións* (Duschl & Bybee, 2014). A elección de examinar en profundidade estas prácticas, vén dada polas oportunidades de participar nelas fornecidas polos proxectos, cuxo deseño foi decidido polas mestras.

O obxectivos xeral de investigación, *examinar como participa o alumnado de educación infantil nas prácticas científicas e como evoluciona esta participación ao longo da etapa, de primeiro a terceiro curso de educación infantil,* foi desglosado en catro obxectivos máis precisos. Os tres primeiros refírese ao alumnado, mentres que o último refírese ás estratexias das docentes.

O primeiro obxectivo de investigación é:

Examinar que características ten o uso de probas polo alumnado de educación infantil, como evoluciona ao longo da etapa, e cal é o papel da observación cun propósito neste uso de probas.

Foi expandido nas seguintes preguntas de investigación:

1) Que características ten o uso de probas polo alumnado de educación infantil e como se reflicte este uso no desenvolvemento de datos en probas? Cales son as diferenzas no uso de probas entre primeiro e terceiro curso de educación infantil?

2) Que formas de obter probas son construídas conxuntamente polo alumnado e as mestras durante o proxecto? Cal é o papel da *investigación cun propósito* neste contexto e cales son as súas características? Cales son as diferenzas nas formas de obter probas entre o alumnado de primeiro e terceiro curso de educación infantil?

3) Como usa as probas o alumnado de educación infantil para revisar as súas ideas? Cales son as diferenzas no uso de probas entre o alumnado de primeiro e terceiro curso de educación infantil?

O segundo obxectivo de investigación é:

Examinar que características ten o uso e construción de modelos polo alumnado de educación infantil, como evoluciona esta construción ao longo da etapa, e cal é o papel das representacións nesta práctica.

É abordado mediante as seguintes preguntas de investigación:

1) Que significados científicos sobre os caracois son construídos e comunicados polo alumnado de primeiro de educación infantil (3-4

anos) nos seus modelos expresados e como cambian ao longo dun curso?

2) Que tipos de recursos comunicativos e representacionais da clase de ciencias son apropiados polo alumnado de primeiro de educación infantil?

3) Como evolucionan en complexidade as formas en que o alumnado usa e constrúe modelos científicos expresados de primeiro a terceiro curso de educación infantil?

O terceiro obxectivo de investigación é:
Examinar que características ten a construción de explicacións polo alumnado de terceiro curso de educación infantil e como evoluciona ao longo dun curso escolar.
É abordado na seguinte pregunta de investigación:

1) Cales son as características das explicacións do alumnado sobre os cambios de estado en terceiro curso de educación infantil e como evolucionan ao longo do curso escolar?

O cuarto obxectivo de investigación é:
Como apoian as mestras a participación do alumnado nas prácticas científicas e como cambia este apoio (andamiaxe) ao longo da etapa.
Abórdase mediante as seguintes preguntas:

1) Cales son as estratexias empregadas polas mestras de ECE-L e ECE3-P para apoiar a participación do alumnado nas prácticas científicas?

2) Cales son as características e os beneficios de andamiar a construción de representacións científicas en educación infantil?

3) Como é modulada a intensidade da andamiaxe de ECE1-L a ECE3-L?

A orixinalidade e pertinencia deste estudo radica en que, por unha banda, existen poucos estudos sobre a participación de alumnado destas idades nas prácticas científicas e, por outra banda, lévase a cabo un estudo lonxitudinal, acompañando a un grupo durante toda a etapa de educación infantil, o que permite seguir a evolución da súa participación nas prácticas, así como unha análise en profundidade do contexto e accións dos participantes no estudo.

1.3 ORGANIZACIÓN DA TESE

A tese está organizada en tres partes: fundamentación, resultados da investigación e conclusións e implicacións didácticas. A primeira está redactada en galego, e as outras dúas en inglés.

A primeira parte, fundamentación, comprende tres capítulos: *introdución*, *marco teórico* e *metodoloxía*. Neste primeiro capítulo, *introdución*, preséntanse brevemente os antecedentes da investigación, os obxectivos da mesma e a súa relevancia.

No segundo capítulo, *marco teórico*, discútense os campos de coñecemento nos que se fundamenta a tese. Tres deles pertencen á didáctica das ciencias experimentais: a teoría socio-cultural da aprendizaxe, a aprendizaxe das ciencias en educación infantil e as prácticas científicas. O cuarto campo teórico no que se fundamenta a tese e a semiótica social da comunicación visual.

O terceiro capítulo, *metodoloxía*, estrutúrase en catro apartados. No primeiro preséntanse os obxectivos de investigación. No segundo discútense o enfoque cualitativo e as estratexias metodolóxicas dos estudos de caso e lonxitudinais. No terceiro, preséntanse o contexto e os participantes. Por último, no cuarto abórdanse a recollida de datos e os métodos de análise.

A segunda parte da tese, formada por catro capítulos, aborda os resultados de investigación. No capítulo 4 discútense os resultados con respecto ao uso de probas por alumnado de educación infantil; como evoluciona este uso do primeiro ao terceiro curso de educación infantil, e cal é o papel da *observación cun propósito* nesta práctica.

No capítulo 5 abórdanse os resultados sobre a participación do alumnado en prácticas de modelización e como evoluciona esta participación entre o primeiro ao terceiro curso de educación infantil.

No capítulo 6 discútense os resultados sobre a construción de explicacións científicas en terceiro curso de educación infantil e a súa evolución ao longo dun curso escolar.

No capítulo 7 abórdanse os resultados sobre como apoian as mestras de educación infantil a participación do alumnado nas prácticas científicas e como a súa andamiaxe é modulada ao longo da etapa.

As *conclusións* abórdanse no capítulo 8. Nel discútense as conclusións e implicacións didácticas derivadas do estudo, así como as limitacións do mesmo e as futuras liñas de investigación que xorden dos resultados.

2 MARCO TEÓRICO

Os fundamentos da tese proceden de catro campos de coñecemento. Tres relaciónanse coa didáctica das ciencias: a teoría socio-cutural da aprendizaxe, a aprendizaxe das ciencias en educación infantil e as prácticas científicas. O cuarto campo teórico no que se fundamenta este traballo é a semiótica social da comunicación visual.

2.1 A Aprendizaxe na Perspectiva Sociocultural

Este estudo sitúase nunha perspectiva que considera que a aprendizaxe ten unha natureza dialóxica (Bruner, 1966; Vygotsky, 1978). Contemplamos a aprendizaxe máis como un proceso social que individual, mediado polas interaccións sociais nun contexto dado, no que os aspectos culturais e sociais inflúen no *que* se aprende e en *como* se aprende. Vygotsky distingue tres niveis nas interaccións que median a aprendizaxe: o interactivo, que se refire á interacción con individuos e con materiais e artefactos; o estrutural, que se refire aos valores transmitidos por estruturas sociais como familia e escola; e o cultural, que se refire á cultura na que á persoa se cría e que inclúe dimensións como, a linguaxe ou a tecnoloxía. Segundo Vygotsky (1978), as persoas nacen cunhas funcións mentais elementais, como a capacidade de memorizar. Mediante as interaccións sociais van desenvolvendo e adquirindo funcións mentais superiores, por exemplo, o pensamento crítico. A aprendizaxe, pois, inflúe no desenvolvemento cognitivo: “learning is a neccessary and universal aspect of the process of developing culturally organized, specifically human psychological function” (Vygotsky, 1978, p. 90). A linguaxe ten un rol crítico no desenvolvemento cognitivo, xa que é o medio polo que é transmitida máis frecuentemente a información de adultos a nenos; permite a comunicación entre pares; e media o pensamento interno dunha persoa (Vygotsky, 1991). Bruner (1996) apunta que a aprendizaxe é un produto cultural e considera que son os membros dunha comunidade quen constrúen significados mediante a negociación, mediada pola linguaxe. Brooks (2005) considera que os debuxos das nenas e nenos tamén son mediadores da aprendizaxe porque serven para comunicar, negociar e construír significados.

Vygotski (1978) propuxo que a aprendizaxe ten lugar no que denominou *zona de desenvolvemento proximal* (ZPD), comprendida entre o que una persoa é capaz de facer por si mesma e o que é capaz de facer guiada por unha persoa máis experta. Dentro da teoría socio-cultural da aprendizaxe, esta guía coñécese como *andamiaxe* (*scaffolding*). Vygotski non usou o termo andamiaxe, que foi introducido por primeira vez por Wood, Bruner e Ross (1976). Esta metáfora baséase na función dos andamios na construción: son unha estrutura necesaria e temporal, que se retira cando xa non se precisa. Do mesmo xeito, a andamiaxe educativa é progresivamente retirada a medida que a persoa acada a autonomía para resolver problemas ou realizar tarefas por si mesma. Na educación infantil, as interaccións que teñen lugar coa mestra ou mestre son moi importantes: no contexto da aula, é a persoa experta que guía a aprendizaxe do alumnado, menos experto. "As a teacher you do not wait for readiness to happen; you foster or 'scaffold' it by deepening the child's powers at the stage where you find him or her now" (Bruner, 1996, p. 120). A andamiaxe pode ter como obxectivo fornecer apoio na dimensión cognitiva, como facilitar a aprendizaxe dos contidos da disciplina; na metacognitiva, como apoiar a comprensión do sentido da tarefa; e na afectiva, como manter a motivación e o controlar a frustración ou a perda de interese (Van de Pol, Volman & Beishuizen, 2010).

Os elementos clave da andamiaxe son a modulación ou continxencia, o esvaecemento e a transferencia de responsabilidade (Reigosa & Jiménez-Aleixandre, 2007; Van de Pol et al. 2010). A continxencia ou modulación refírese á continua avaliación da persoa aprendiz por parte da docente para poder adaptar a andamiaxe ás súas necesidades. O esvaecemento, á desaparición progresiva da andamiaxe. A transferencia de responsabilidade refírese ao maior control por parte do aprendiz e menor control por parte da mestra ou mestre. Pearson e Gallagher (1983) propoñen o *Gradual Release of Responsibility Model*, o cal implica tres fases: responsabilidade da persoa docente, responsabilidade conxunta docente-estudante; e responsabilidade do estudante. Autores como Donato (1994) e Moll (1990) expanden a metáfora da andamiaxe ao "collective scaffolding" entre pares, referíndose á colaboración entre o alumnado ao traballar en grupo, que lles permite acadar resultados que non acadarían individualmente.

2.2 A Aprendizaxe das Ciencias en Educación Infantil

Un dos informes da OECD (2012) mostra que a aprendizaxe das ciencias desde educación infantil beneficia o rendemento posterior do alumnado neste eido. Isto pon de manifesto a importancia de documentar como nenas e nenos pequenos aprenden ciencias, a fin de apoialos de forma axeitada. O interese en saber como nenas e nenos de educación infantil aprenden ciencias tense incrementado nos últimos anos e publícanse un maior número de traballos centrados nestas idades (Areljung, Ottander & Jue, 2017). Os congresos máis relevantes da área contan con liñas específicas sobre estas idades (European Science Education Research Association (ESERA), *Early Ages*; National Association for Research in Science Teaching (NARST), *Early Years preK-6*). Porén, ao facer unha busca coas palabras clave "kindergarten", "preschool" e "early childhood" nas revistas de didáctica das ciencias de maior impacto (*International Journal of Science Education; Journal of Research in Science Teaching; Research in Science Education; Science Education; Science & Education*) no período comprendido entre xaneiro de 2013 e agosto de 2017, comprobamos que o número de estudos centrados en niveis iniciais, especialmente en educación infantil, é moito menor que en niveis educativos máis altos. A continuación trátanse os aspectos máis salientables que discute a investigación sobre a aprendizaxe da ciencia por nenas e nenos pequenos.

Tense afirmado que as nenas e nenos son naturalmente curiosos e realizan observacións e preguntas sobre o mundo que os rodea, de xeito que están predispostos para aprender ciencia (Cabe Trundle, 2015; Patrick & Mantzicopoulos, 2015). Fleer e Pramling (2015) puntualizan que é necesario axudalos a fomentar esa curiosidade para apoiar a súa participación en ciencias. As nenas e nenos fan uso das súas experiencias cotiás para explicar o mundo que os rodea, moitas veces de xeito consistente (Hadzigeorgiou, 2015). Fleer e Pramling (2015), apuntan que os conceptos cotiás, construídos polos nenos a partires das súas experiencias do día a día, son centrais para que nenas e nenos desenvolvan conceptos científicos. Segundo Vygotsky (1978), o desenvolvemento de ambos tipos de conceptos vai unido:

> Whether we refer to the development of spontaneous concepts or scientific ones, we are dealing with the development of a unified process of concept formation. By its very nature, however, it remains a unified process. It is not a function of struggle, conflict, or antagonism between two mutually exclusive forms of thinking (p. 177).

Durante 30 anos, gran parte da investigación educativa en ciencias centrouse en caracterizar as ideas do alumnado, sobre todo de secundaria, en diferentes campos da ciencia, como forzas, evolución, xenética, luz ou flotación. Durante as décadas de 1970 e 1980 foron publicados numerosos traballos nesta liña, que deron lugar ao que se coñece como *Children's Science*, ou ideas alternativas do alumnado en ciencia (e.g. Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg, 1985). As ideas alternativas considéranse as primeiras respostas do alumnado, diferentes das da comunidade científica, son resistentes ao cambio, persistentes no tempo e non sempre dependentes da idade. Na última década, diminuíu o número de traballos sobre as ideas alternativas do alumnado e outras liñas de estudo, como a argumentación, as cuestións socio-científicas e as progresións de aprendizaxe, foron tomando o seu lugar.

Así, sobre o alumnado máis novo, incrementouse o interese por coñecer como o nenas e nenos de educación infantil constrúen coñecemento científico en contextos formais (e.g. Siry, Brendel & Frisch, 2016; Ergazaki, Alexaki, Papadopoulou & Kalpakiorie, 2014) e non formais (e.g. Plummer & Ricketts, 2016); por desenvolver programas educativos innovadores (e.g. *Preschool Pathways to Science* (PrePS), Gelman & Brennemman, 2012; *Science Literacy Program* (SLP), Samarapungavan, Mantzicopoulos & Patrick, 2008); ou por coñecer a motivación das nenas e nenos e as posibles diferenzas de xénero no seu interese e rendemento en ciencias (e.g. Leibham, Alexander & Johnson, 2013). A continuación, discutimos agunhas destas aportacións.

A capacidade dos nenos e nenas pequenos de implicarse en indagación científica ten sido obxecto de debate. No ano 1995, Kathleen Metz publicou un traballo na revista *Review of Educational Research* no que discutía que a capacidade dos nenos para participar en indagación estivera limitada polo seu grao de desenvolvemento cognitivo. No contexto deste debate Deanna Kuhn (1997) respondeu, na mesma revista, que os estudos de desenvolvemento cognitivo poden ser vistos como unha guía e non como restricións. Metz (1997) argumentou que moitas das dificultades presentadas por nenas e nenos pequenos en indagación respondían á súa falta de dominio de contidos do eido científico, pero non a restricións cognitivas. Nos anos seguintes, Metz (2008; 2011) desenvolveu un programa de investigación co obxecto de examinar até que punto a instrución afecta ás capacidades do alumnado máis novo. A partir desta investigación, concluíu que algúns dos estudos cognitivos subestiman as capacidades de nenas e nenos xa que non teñen en conta o impacto positivo da formación. Posteriormente, nunha revisión de literatura sobre o desenvolvemento cognitivo, Sandoval, Sodian, Koerber e Wong (2014) concluíron que as nenas e nenas pequenos posúen as capacidades necesarias para implicarse en ciencias, que o ensino pode potenciar.

Tanto o *curriculum* como a andamiaxe da persoa docente revélanse como algúns dos factores cruciais para a aprendizaxe das ciencias durante primeiros anos de escolarización. Para desenvolver o programa *Preschool Pathways to Science* (PrePS), Gelman e Brenneman (2012) baseáronse tanto en estudos de desenvolvemento cognitivo como na literatura sobre o ensino das ciencias. Segundo eles, os nenos e nenas, por si sós, igual que acontece coas persoas adultas, non poden actuar constantemente conforme aos modos da ciencia, pero salientan a pertinencia de cambiar a perspectiva, de cara a coñecer o que son capaces de facer, en vez de partir das súas dificultades. Gelman e Brenneman destacan a necesidade de que o alumnado dispoña de tempo para a comprensión, e a importancia de promover o seu papel activo e partir do que lle é próximo, dado que resulta máis doado facer conexións co coñecemento xa construído.

Segundo Siry (2013), no contexto dos proxectos de indagación, as interaccións entre o alumnado posibilitan a produción de coñecemento científico. Samarapungavan e colegas (2008) implementaron o Science Literacy Project (SLP), proxecto de iniciación á alfabetización científica cun currículo innovador, en aulas de nenos de cinco anos. Compararon a comprensión que mostraba sobre os procesos de indagación unha clase que traballara unha unidade do proxecto coa mostrada por outra clase, da mesma escola e de características demográficas similares, pero que non participara neste proxecto de innovación. A comprensión era mellor na primeira das aulas. Inan e Inan (2015) indican que cunha andamiaxe apropiada, nenas e nenos poden realizar proxectos de indagación que impliquen o que denominan as *3H: hands-head-heart on activities*, actividades prácticas, que os fagan reflexionar e que os motiven. Andersson e Gullberg (2014) sinalan a importancia da competencia pedagóxica da mestra ou mestre na educación infantil, e apuntan aos beneficios de facer preguntas que estimulen a exploración.

Leibham, Alexander e Johnson (2013) levaron a cabo un estudo lonxitudinal en aulas estándar a fin de coñecer se o interese e autoestima no eido da ciencia nos tramos de idade 4-6 e 6-8 tiña un efecto no rendemento nesta materia aos 8 anos. Por unha banda, encontraron que, desde niveis iniciais, os nenos mostraban maior interese polas ciencias que as nenas. No caso das nenas, ademais, encontraron que existía unha relación entre o maior interese en ciencias e maior autoestima, e que este influía no seu rendemento posterior. Mais estas diferenzas poden ter que ver co enfoque da instrución: Patrick, Mantzicopoulos e Samarapungavan (2009) non observaron diferenzas nin no rendemento nin na motivación entre as nenas e nenos que participaron no proxecto SLP.

Siry (2014) sinala que o ensino das ciencias en educación infantil é complexo e que a dimensión emocional é de gran relevancia. Fleer (2013) apunta que as emocións son determinantes para a cognición, sinalando a potencialidade da *affective imagination* na educación infantil. Por exemplo, na aprendizaxe de conceptos científicos a través de contos nos que os nenos empatizan coas personaxes.

Unha liña de traballo interesante nestas idades examina a importancia e posibilidades do xogo na construción de conceptos científicos, desde a perspectiva de que este é unha actividade que posibilita a interacción do neno coa súa contorna (e.g. Akman & Özgül, 2015; Fleer, 2011; Fleer & Pramling, 2015).

Como conclusión, pódese dicir que, para apoiar as capacidades de nenas e nenos é importante a motivación, partir dos seus intereses e proporcionarlles ambientes de aprendizaxe ricos que fomenten o seu papel activo e as interaccións entre eles.

2.3 As Prácticas Científicas

Neste apartado, primeiro preséntase a perspectiva da ciencia como conxunto de prácticas e, a continuación, discútese a importancia da implicación do alumnado nas prácticas científicas. Por último, discútense as prácticas científicas relevantes para este estudo: argumentación en base a probas, uso e construción de modelos, construción de explicacións e observación.

2.3.1 A Ciencia como un Conxunto de Prácticas

Osborne (2014) subliña que cada campo de coñecemento ten normas, valores e criterios epistémicos propios. Resalta que o coñecemento científico baséase empiricamente, depende de inferencias, é socialmente negociado, non existindo un método único para a súa construción. Segundo este autor, a investigación non existe independentemente das teorías que pretende examinar, da análise e interpretación dos datos e da argumentación. O coñecemento científico pode ser considerado unha construción cultural: “A cultural-historical reading of science education would position science as a form of cultural knowledge that is historically and collectively formed and understood, rather than as something that is located within the individual” (Fleer & Pramling, 2015; p. 10). A comunidade científica interacciona negociando e lexitimando paradigmas e métodos válidos para a construción do coñecemento científico nun determinado contexto social. O conxunto de prácticas sociais nas que a comunidade científica toma parte e mediante as que é construído o coñecemento científico son as *prácticas epistémicas* desta disciplina. Kelly (2008, p. 99) defíneas como “the specific ways members of a community propose, justify, evaluate, and legitimize knowledge claims within a disciplinary framework”.

As *prácticas epistémicas* e as *prácticas científicas* están estreitamente relacionadas entre sí, de xeito que en ocasións ambos termos úsanse indistintamente. Jiménez Aleixandre e Crujeiras (2017) propoñen que ambos significados se solapan, sendo as prácticas epistémicas un construto máis amplo, e as prácticas científicas o desempeño das prácticas epistémicas nun contexto de aprendizaxe ou nunha área de contido determinada (ver Figura 2.1). Porén, segundo as autoras, certas prácticas científicas como, por exemplo, tomar medidas, non formarían parte das prácticas epistémicas.

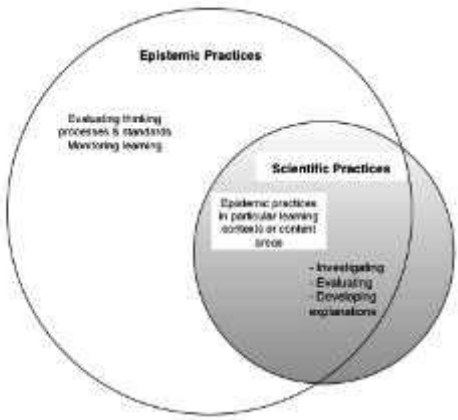


Figura 2.1. Prácticas epistémicas e científicas (Jiménez-Aleixandre & Crujeiras, 2017, p.71)

A visión da ciencia como un conxunto de prácticas (Osborne, 2014) é consistente cunha visión da aprendizaxe da ciencia que implique a participación do alumnado nestas. Segundo Bruner (1996), a mellor forma de aprender a cultura, discurso e contidos dun campo de coñecemento é mediante a participación nas prácticas desde campo. Na mesma liña, Osborne (2014) propón que, para aprender ciencias, o alumnado debe tomar parte en prácticas que o axuden a desenvolver máis profunda e amplamente a comprensión de que sabemos, como o sabemos, e os procedementos epistémicos que orientan a práctica. Para se aproximar a este modelo de ciencia, o alumnado non debe ser consciente só do "que sei", senón tamén de "como" e "por que" sei. Moitos destes aspectos "only have a meaning when students are asked to engage in selected scientific practices" (Osborne, 2014, p. 581).

Na última década, o número de traballos de investigación acerca do ensino das ciencias que versan sobre a implicación do alumnado nas prácticas tense incrementado (e.g. Chinn, Buckland & Samarapungavan, 2011; Greene, Sandoval, & Bråten, 2016; Pluta, Chinn & Duncan, 2011). Tamén os documentos curriculares recollen esta orientación, recomendando a participación do alumnado nas prácticas da comunidade científica, entre outros, co obxectivo de facilitar a comprensión de como os científicos constrúen o coñecemento (e.g. OECD, 2015; National Research Council, NRC, 2012). Andamiar a participación do alumnado de K-1 nas prácticas científicas suscita desafíos para o profesorado (Merritt, Chiu, Peters-Burton & Bell, 2017).

O marco do National Research Council (NRC, 2012) estadounidense para o ensino das ciencias K-12 (o que no sistema español correspondería de 3º de educación infantil ata 2º de Bacharelato) desenvólvese a partir da idea de que o alumnado debe tomar parte en prácticas científicas de cara a aprendizaxe dunha serie de conceptos clave, *core ideas,* da disciplina, e de conceptos transversais, *crosscutting concepts,* que son aqueles que atravesan todas as disciplinas científicas, como a identificación de *pautas*, ou das relacións *causa-efecto.* Este conxunto de conceptos permanece constante ao longo dos cursos, pero é ampliado e cada vez máis sofisticado a medida que se avanza nos niveis educativos. O emprego do termo *practice* e non *skill* xustifícase pola necesidade de coñecemento específico do contido que demanda cada unha das prácticas, que vai máis aló do dominio dunha destreza. As oito prácticas científicas básicas identificadas nos documentos do NRC (2012) e *New Generation Science Standards* (NGSS) (2013) son:

- Formular cuestións científicas
- Construír e usar modelos
- Planificar e levar a cabo investigacións
- Analizar e interpretar datos

- Usar razoamento matemático e computacional
- Construír explicacións
- Argumentar en base a probas
- Obter, avaliar e comunicar información

A Organización para a Cooperación e o Desenvolvemento Económico (OECD) avalía a alfabetización científica do alumnado dos países membros da OECD no marco de avaliación do Program for International Students Assesment (PISA) (e.g. OECD, 2012; 2015). Desde o ano 2006, o marco estrutura a avaliación da aprendizaxe en base á adquisición de competencias básicas (OECD, 2006). A competencia é a capacidade de poñer en práctica o coñecemento construído en contextos e situacións novas e integra conceptos, destrezas e actitudes (Jiménez Aleixandre, 2010; Pro, 2012). No marco de avaliación PISA (OECD, 2016), a competencia científica ven estruturada en tres sub-competencias, definidas como:

> "The first is the ability to *provide explanatory accounts of natural phenomena* (…). Such an ability requires a knowledge of the fundamental ideas of science and the questions that frame the practice and goals of science. The second is the knowledge and *understanding of scientific enquiry* to: identify questions that can be answered by scientific enquiry; identify whether appropriate procedures have been used; and propose ways in which such questions might be answered. The third is the competency to *interpret and evaluate data and evidence* scientifically and evaluate whether the conclusions are justified." (OECD, 2016, p.21)

As tres competencias científicas da OECD (2016), á súa vez, conteñen as prácticas propostas por NRC (2012). Jiménez-Aleixandre e Crujeiras (2017) propoñen unha correspondencia entre as tres grandes dimensións das prácticas propostas polo NRC (2012): *evaluate and design scientific inquiry*, *interpret data and evidence scientifically*, e *explain phenomena scientifically*; e as tres competencias da OECD. As tres dimensións están interrelacionadas entre sí (Bell, Bricker, Tzou, Lee & Van Horne, 2012) e moitas veces teñen lugar simultaneamente.

Tanto os currículos derivados da Lei Orgánica de Educación (LOE)

(MEC, 2006) coma os derivados da Lei Orgánica para a Mellora da Calidade Educativa (LOMCE) (MECD, 2013), teñen en conta a noción de competencia para o seu desenvolvemento. A lexislación da educación infantil en Galicia (Consellería de Educación e Ordenación Universitaria, 2009a; 2009b) data de 2009 e non se viu modificada pola LOMCE, que si afectou á lexislación doutros niveis educativos. No currículo do segundo ciclo da educación infantil (3 a 6 anos de idade), no apartado referido á competencia de *aprender a aprender* apúntase ao fomento da formulación de hipóteses: *"Poténciase a formulación de hipóteses, contrastándoas coas das outras persoas e buscando respostas e explicacións a diferentes fenómenos."* (2009b, p. 185-186). A continuación, recoméndase a participación en proxectos de investigación e construción de representacións: "*Particípase en proxectos de grupo de investigación, expresando as actividades realizadas e os resultados obtidos mediante diferentes representacións."* (2009b, p. 186). No apartado sobre o *coñecemento do mundo físico*, proponse a introdución ao pensamento científico *"potenciando habilidades de investigación: formular hipóteses, recoñecer evidencias, observar, formular interrogantes, descubrir alternativas, verificar, predicir, xerar novas ideas e solucións…"* (2009b, p. 189). As indicacións deste documento non son tan específicas como as dos NGSS (2012) estadounidenses, nos que veñen desenvolvidas *expected performances* para cada unha das prácticas en cada nivel educativo, e contextualizadas en relación a un concepto clave concreto.

A continuación, discutimos as tres prácticas dos NGSS *Argumentar en base a probas*, *Construír e usar modelos* e *Construír explicacións*. A *observación*, aínda que non é diferenciada como práctica nin no marco da OECD (2016) nin no de NRC (2012), forma parte doutras prácticas, como por exemplo planificar e levar a cabo investigacións (Duschl & Bybee, 2014), é discutida pola súa relevancia neste estudo.

2.3.2 A Argumentación en Base a Probas

A argumentación é a avaliación de enunciados de coñecemento en base ás probas dispoñibles; e tamén a capacidade de defender a validez dun enunciado fronte a outros (Jiménez Aleixandre, 2010; Jiménez-

Aleixandre & Erduran, 2008). Segundo o modelo de Toulmin, amplamente empregado na didáctica das ciencias, a estrutura dun argumento componse de tres compoñentes básicos: a *conclusión*, que é o enunciado de coñecemento, as *probas* empregadas para sustentalo e a *xustificación* que conecta os dous anteriores. Ademais, un argumento pode incluír outros elementos: o *coñecemento básico* ou teoría na que se basea a xustificación (ben de xeito implícito ou explícito); os *cualificadores modais* que expresan o grao de certeza da conclusión; e as *refutacións*, as cales cuestionan as probas aportadas a favor do enunciado oposto. Algúns autores (e.g. McNeill, 2011) usan o termo *reasoning* para referirse a xustificación. A continuación, discutimos os compoñentes *conclusión* e *proba*, de acordo aos traballos nos que se fundamenta esta tese.

McNeill e Krajcik (2008), definen conclusión como un enunciado que responde á pregunta orixinal. Para Kuhn e Pearsall (2000), un enunciado de coñecemento pode ser considerado unha conclusión teórica se é potencialmente falseable por probas. Kuhn e Pearsall (2000) identifican catro tipos de conclusións teóricas (*theoretical claims*), de crecente complexidade: 1, *category claim*; 2, *event claim*; 3, *causal or explanatory claim*; e 4, *explanatory system claim*. Un tipo de conclusións especialmente relevantes para as ciencias naturais son as explicacións causais (Jiménez-Aleixandre, 2010).

McNeill (2011), define as probas como datos que se usan para responder a unha pregunta, resolver un problema ou facer unha decisión. Para McNeill e Krajcik (2008), os datos son probas se son axeitados e suficientes para xustificar a conclusión.

En canto á necesidade de incluír a argumentación no ensino das ciencias, para Jiménez Aleixandre (2010), promove o desenvolvemento do pensamento crítico; e contribúe no desenvolvemento da competencia de aprender a aprender. Segundo Jiménez-Aleixandre e Erduran (2008, p.4): "Argumentation is a form of discourse that needs to be appropriated by students and explicitly taught through suitable instruction, task structuring and modelling".

No marco do contínuum Evidence Explanation (E-E) (Duschl, 2008), o alumnado emprega probas nas súas explicacións, seguindo tres etapas:

1) Seleccionar ou xerar datos que constitúan probas
2) Usar probas para identificar pautas (*patterns*) ou modelos
3) Empregar os modelos ou pautas para propoñer explicacións.

O paso dunha etapa a outra, implica que o alumnado realiza xuízos epistémicos sobre o "que conta" como datos, probas ou explicacións.

Entre as dificultades máis frecuentes do alumnado para argumentar a investigación identifica, entre outras: a dificultade para coordinar conclusións e probas por parte de estudantes de educación secundaria (Jiménez-Aleixandre, Bugallo & Duschl, 2000); o uso de criterios inadecuados para avaliar as probas (Hogan & Maglienti, 2001); ou os problemas para explicar como unha proba apoia a conclusión (Sandoval & Millwood, 2005). McNeill (2011) examinou cambios nos conceptos de explicación, argumentación e proba ao longo dun curso escolar. Encontrou que a maioría do alumnado de 10 anos non mencionaba explicitamente os datos cando discutían sobre as probas. Songer e Gotwals (2012) levaron a cabo un estudo sobre progresións de aprendizaxe na construción de explicacións baseadas en probas en primaria, no que encontraron que o aspecto máis difícil para o alumnado de 9-10 anos era a xeración de probas, mentres que para o de 10-11 anos era conectar probas e conclusións mediante a xustificación.

Os contextos dialóxicos fornecen ao alumnado de oportunidades para mellorar a súa capacidade de argumentar. Os resultados dun estudo con alumnado de 10 e 11 anos (Chen, Hand e Park, 2016) indican que a participación en debates de aula, posibilitou que o alumnado prestara atención á coherencia dos seus propios argumentos, previamente elaborados por escrito. Ao revisar os seus argumentos escritos despois das roldas de debate, os estudantes, por unha banda, mellorábanos; e por outra banda, percibían a utilidade das críticas dos seus compañeiros. Kim (2016) documenta como nenas e nenos de 7 a 9 anos solucionaron problemas de xeito colectivo, mediante a avaliación activa de teorías e probas, chegando a consensos mediante razoamento dialóxico.

En canto a como o alumnado de educación infantil usa probas para apoiar conclusións, só conseguimos localizar tres traballos. Gotwals, Hokayem e Wright, (2014), documentaron que nenas e nenos de 5 anos, con oportunidades de aprendizaxe apropiadas, poden apoiar as súas conclusións con probas. Plummer e Ricketts (2016), examinaron como nenas en nenos entre 3 e 6 anos de idade foron capaces, usando modelos físicos de cráteres, de xerar probas. Estas autoras documentaron como os nenos elaboraron conclusións a partir de modelos e probas, tanto xeradas por eles mesmos, como proporcionadas pola condutora da actividade. Nun estudo lonxitudinal no que participaron 138 nenos de diferentes perfís socioeconómicos, Piekny, Grube e Maehler (2014), documentaron que a capacidade de avaliar probas evoluciona dos 4 a 6 anos de idade. Para este estudo, traballaron de xeito individual cos nenos. Estes realizaron tarefas deseñadas para o propósito da investigación, sobre as que foron entrevistados. É dicir, non se examina a evolución das prácticas de avaliación e uso de probas na construción de argumentos nun contexto de aprendizaxe. Nos outros dous estudos anteriormente citados, analízase o uso de probas polos participantes implicados en tarefas no contexto da aula de educación infantil (Gotwals, Hokayem & Wright, 2014) e nun obradoiro de ciencia nun museo (Plummer & Ricketts, 2016), respectivamente. Unha contribución ao estudo do uso de probas polo alumnado máis novo é o artigo de Monteira e Jiménez-Aleixandre (2016), sobre unha parte desta investigación.

Nesta tese examinamos o significado de proba para o alumnado de entre 3 e 6 anos de idade no contexto de proxectos de indagación na aula; exploramos como xera datos e como os selecciona e usa como probas; e como usa as probas nos seus diálogos argumentativos.

2.3.3 Uso e Construción de Modelos

Neste apartado defínese a práctica de uso e construción de modelos e o seu papel en ciencias. A continuación, discútense os diferentes modos nos que un modelo pode ser expresado; e a relación entre modelos e representacións.

Gilbert, Boulter e Elmer (2000) definen modelo como unha representación dun fenómeno inicialmente producido para unha finalidade específica. Un modelo pode servir para facer visibles entidades abstractas, describir ou simplificar fenómenos; e servir de base de predicións e explicacións científicas (Gilbert, 2004). Un modelo é unha representación parcial, na que se inclúen certos aspectos dun fenómeno natural, omitíndose outros. Como tal, un modelo sempre presenta limitacións e é importante que o alumnado aprenda a recoñecelas (NGSS Lead States, 2013).

"A model is a *product* with a distinct purpose. We design models selectively, systematically, and deliberately. Building a model is an end in itself. You have a purpose for every model that you build; every sentence that you utter, for example, is a model" (Gilbert, 2011, p. 54).

Desde esta perspectiva, os debuxos e as explicacións dos nenos, producidos cun obxectivo específico, poden ser considerados modelos expresados. Porén, neste traballo, as explicacións identificadas no discurso do alumnado son analizadas con base á literatura específica sobre explicacións científicas, que é discutida máis adiante.

A fin de ser compartidos, os *modelos mentais*, representacións privadas e persoais de cada individuo, teñen que ser transformados en *modelos expresados* (Gilbert et al., 2000). Posto que a comunicación é multimodal, os modelos poden ser expresados en diferentes modos semióticos. Os modo de expresión máis relevante na nosa investigación é o modo *visual*, que implica o uso de formas gráficas e pictóricas, e no que se encadran, entre outros, os debuxos dos nenos. Ademais, para este traballo tamén son importantes o modo *concreto*, que implica o uso de materiais; e o *xestual*, que implica acción (Gilbert et al. 2000). A visualización xoga un papel central no ensino da ciencia, xa que permite que o alumnado sexa capaz de moverse a través de diferentes modos de representación (Gilbert, 2005). Wilson e Bradbury (2016) apuntan que a representación de conceptos científicos en varios modos por parte de nenas e nenos supón beneficios para a súa aprendizaxe.

Debuxar pode resultar máis accesible para nenas e nenos pequenos que escribir, polo que é unha ferramenta importante nestas idades para visualizar e comunicar as súas ideas. Segundo Brooks (2009), pode ser un dos primeiros esforzos de abstracción dun neno, xa que implica a produción de símbolos: "The ability to visualise ideas, concepts and problems can help move children to higher levels of thinking" (Brooks, 2009, p.320). Noutro estudo, Brooks (2005) examinou os diálogos do alumnado de 5 e 6 anos de idade mentres debuxaba. Segundo esta autora, brindarlles oportunidades para que revisen os seus debuxos e dialogar sobre estes, ten un gran potencial de cara a exploración e representación, por parte dos nenos, de ideas complexas.

Schwarz et al. (2009), definen a modelización a partir da práctica e o metacoñecemento que a guía. Identifican os seguintes elementos da práctica: usar, construír, avaliar e revisar modelos científicos. Segundo o marco de NRC, "Modeling can begin in the earliest grades, with students' models progressing from concrete "pictures" and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades." (2012, p. 58). Nunha revisión sobre *Model Based Learning* (MbL), Louca e Zacharia (2012) localizaron poucos estudos en primaria e ningún en niveis inferiores sobre como modelizan as nenas e nenos. Posteriormente, estes autores publicaron un estudo que se centrou nas fases seguidas polas nenas e nenos de 5 anos ao implicarse en modelización (Louca & Zacharia, 2015). Encontraron que as fases que seguen ao modelizar, diferían das seguidas por alumnado de 10 anos e experto nesta práctica e que o papel da persoa docente toma máis importancia en educación infantil. Por exemplo, apoiando procesos como a avaliación do modelo producido. No estudo de Plummer e Ricketts (2016), os nenos de entre 3 e 6 anos utilizaban modelos físicos, cos que experimentaban, para xerar datos primarios. Plummer e Ricketts encontraron que foron capaces de construír e revisar modelos dun fenómeno científico baseándose en datos secundarios, como fotos e vídeos.

Os modelos expresados son denominados *representacións externas* por Pérez-Echeverría e Scheuer (2009). Estas autoras concíbenas coma ferramentas de aprendizaxe, producidas en interacción cos modelos. Consideran que os modelos mentais son construídos en interacción coa produción de representacións. É dicir, o proceso non é unha secuencia lineal que vai desde conceptos e modelos mentais totalmente desenvolvidos até o produto, a representación, senón que esta relación é bidireccional.

Autores como Danish e Phelps (2011), Fleer e Pramling (2015), ou Pérez-Echeverría e Scheuer (2009), usan o termo *prácticas representacionais* para referirse ás prácticas mediante as que o alumnado produce representacións coas que accede ao mundo. No proceso de elaborar as representacións o alumnado toma decisións sobre o que inclúe nelas. Nun estudo con nenos de 5 e 6 anos, Danish e Enyedi (2007) identificaron factores que inflúen nas decisións sobre que representar: a interacción cos compañeiros, as indicacións da tarefa; e o que na cultura da aula se considera realizar "ben" a tarefa. Indican que o proceso de toma de decisións pasa por negociacións complexas. Danish e Phelps (2011) examinaron o discurso do alumnado de 5 a 7 anos, mentres realizaba tarefas de debuxo. Identificaron os seguintes cambios despois da instrución: o alumnado referíase con termos e indicacións máis exactos nas súas discusións sobre o contido e os debuxos, e había maior presenza de avaliación das representacións entre compañeiros na discusión de grupo mediada pola mestra. Danish e Saleh (2014), nun estudo con alumnado de entre 6 e 9 anos, mostraron que cando elaboraban representacións cooperando en parellas, os desempeños eran mellores nas tarefas de síntese, mentres que, cando traballaban individualmente, eran mellores nas tarefas abertas.

As representacións científicas frecuentemente inclúen entidades non observables, por exemplo, ondas electromagnéticas ou átomos. Segundo Gilbert (2004) "a model can include representations both of abstractions and of the material objects on which they act at the same time" (p.117). Tamén Bruner (1996) refírese no seu traballo á diferente natureza das representacións. Segundo el, para poder aprehender a realidade, o ser humano precisa representala, usando tres modos de crecente complexidade, que denomina *enactive*, *iconic* e *symbolic*. O modo *enactivo* implica acción, a codificación (representación) do significado de "bicicleta" ten lugar mediante a acción de montar nela. O modo *icónico* refírese ao uso de imaxes que capturan os trazos distintivos do fenómeno representado, como, por exemplo, unha foto dunha bicicleta. O modo *simbólico* implica o uso dun código, por exemplo a linguaxe: a palabra bicicleta. A natureza icónica e simbólica das representacións ten sido discutida por outros autores. O significado de *representación* nestes traballos é diferente do empregado por Bruner, usando o termo para referirse a unha entidade que substitúe a outra. O modelo semiótico de Peirce (1955) distingue entre símbolos, que son arbitrarios e que substitúen unha entidade, tales como palabras; e imaxes, que poden ser consideradas iconas. Segundo Feinstein (1982), os signos son rexistrados polos humanos, pero non inventados, mentres que os símbolos si, e o seu significado é acordado. Para outros autores (e.g. Goodman, 1976; Huttenlocker & Higgins, 1978) o parecido físico, ou iconicidade, non é relevante, para a función simbólica. Segundo DeLoache (2004), un símbolo convértese nun símbolo como resultado do seu uso para substituír a unha entidade. Segundo esta autora, é preciso dominar os símbolos para formar parte da sociedade. A teoría da semiótica social da comunicación visual, discutida na última sección do marco teórico, fornécenos cunha perspectiva de como poden ser creados significados, na comunicación visual, mediante o modo no que se representa unha entidade, non meramente segundo a entidade representada.

Pódese dicir que a construción dun modelo científico implica representar un fenómeno, mediante unha representación privada, mental; ou pública, compartida con outros. Os debuxos infantís son un tipo de representación moi relevante para o ensino de ciencias na educación infantil. Como modelos, estas representacións son intencionais, xa que nenas e nenos deciden o que é importante incluír nelas.

2.3.4 Construción de Explicacións

Nesta sección primeiro discutimos o que é unha explicación en ciencias e despois facemos unha revisión de como o alumnado se implica na práctica de construción de explicacións.

Unha explicación é un tipo de enunciado de coñecemento. McNeill (2011, p 795) define explicación como "providing an account of how or why a phenomenon occurs and explaining why the natural world works in particular ways". Segundo o marco de PISA (OECD, 2016), para poder construír explicacións sobre fenómenos naturais, é preciso o coñecemento das teorías científicas e das prácticas e preguntas que orientan a disciplina. Zangori, Forbes e Schwarz (2015) indican que unha explicación en base a modelos é a comprensión de como e por que o proceso ocorre, unha expresión dun mecanismo causal. O mecanismo é unha entidade ontolóxica que representa factores causais, os cales poden non resultar intuitivos ou accesibles a través da observación. Russ, Scherr, Hammer, & Mikeska (2008) identifican cinco elementos clave na construción dunha explicación mecanística: describir o estado inicial e final do sistema, as relacións entre elementos do mesmo, propiedades dos mesmos; e os pasos no procesos que conducen dun estado a outro.

Sobre a distinción entre argumentar en base a probas e construír explicacións existen diferentes posicións. Segundo Osborne e Patterson (2011), dado que estas prácticas se solapan, as distincións entre elas poden resultar pouco claras. Berland e McNeill (2012, p.809) responden a Osborne e Patterson, explicando do seguinte xeito a sinerxía entre as dúas prácticas: "scientists constructing explanations for a phenomenon argue about them using evidence and argumentation enables scientists to improve upon their explanations. As such, we see the two practices of explanation and argumentation as having a complementary and synergistic relationship".

As explicacións científicas varían en complexidade. O informe PISA (2006) describe seis niveis de aptitude na capacidade do alumnado para construír explicacións. Estes son definidos segundo como o alumnado aplica os conceptos científicos, como usa modelos e datos; e as relacións causa efecto que expresa. Segundo Perkins e Grotzer (2005), o alumnado está familiarizado con modelos causais simples, axeitados para explicar a vida cotiá, o cal pode dificultar a comprensión dos modelos científicos, máis complexos. Para apoiar ao alumnado na superación desta dificultade, recomendan "draw their [*students*] attention to how they are modelling the causality involved in particular phenomena and encourage more sophisticated causal modelling" (p.119). Perkins e Grotzer (2005) propoñen que a complexidade dos modelos explicativos varía en catro dimensións: a) mecanismo; b) interacción, c) probabilidade e d) axencia (Táboa 2.1). Por exemplo, na dimensión axencia, un modelo explicativo situado no nivel menos complexo consideraría un único axente central, e un situado no máis complexo incluiría axentes emerxentes. Entre ambos extremos situaríanse as cadeas e as redes de causalidade, sendo a rede de maior complexidade que a cadea. Esta taxonomía non pretende suxerir un camiño de desenvolvemento. Aínda así, o incremento de complexidade nunha dimensión pode ir acompañado por un incremento noutras. Perkins e Grotzer indican que os nenos tenden a construír enunciados situados nos niveis menos complexos, aínda que incluso os nenos máis novos poden desenvolver explicacións nos diversos niveis de complexidade contemplados na taxonomía.

Táboa 2. 1. Complexidade nas dimensións que conforman os modelos explicativos (elaboración propia, a partir de Perkins e Grotzer, 2005)

Dimensión	Menor complexidade	Maior complexidade
Mecanismo	Superficial	Subxacente
Interacción	Simple linear	Causalidade baseada en restricións
Probabilidade	Determinística	Probabilística
Axencia	Axente central	Entidades e procesos emerxentes

As explicacións causais sobre fenómenos naturais son un tipo de *claim* (conclusión) moi relevante en ciencias (Jiménez Aleixandre, 2010). Kuhn e Pearsall (2000) definen catro niveis de complexidade para as *theoretical claims* que foron discutidos no apartado de argumentación. Consideramos que estes niveis son aplicables ás explicacións, dado que estas son un tipo especial de conclusión. A Táboa 2.2 recolle a definición de cada tipo de explicación, con exemplos tomados do traballo de Kuhn e Pearsall (2000).

Táboa 2. 2. Niveis de complexidade das explicacións (elaboración propia, a partir de Kuhn e Pearsall, 2000)

Niveis	Definición	Exemplo
1	Identificación de conceptos clave	As plantas son seres vivos
2	Identificación de procesos	A planta morreu
3	Identificación de relacións de causalidade	A planta morreu por falta de sol
4	Identificación de relacións sistémicas	A planta mantense viva debido ao proceso de fotosíntese, que depende de varios factores

O primeiro nivel implica identificar os conceptos clave para o fenómeno. O segundo, identificar os procesos. O terceiro e cuarto nivel implican relacionar conceptos clave e fenómenos cos factores que os determinan: o terceiro nivel implica identificar relacións de causalidade; e o cuarto nivel, identificar relacións sistémicas.

Distintos estudos mostran que o alumnado de primaria é capaz de construír explicacións, cando se lles proporcionan oportunidades de facelo (e.g. McNeill, 2011; Metz, 2011). A construción de explicacións polo alumnado beneficia a aprendizaxe das ciencias (McNeill & Krajcik, 2009; Songer & Gotwals, 2012). Porén, os alumnos reciben moitas explicacións, pero non se lles solicita con tanta frecuencia construílas (Osborne, 2014; Zangori, Forbes & Biggers, 2013). Braaten e Windschitl (2011) indican que, con frecuencia, o alumnado constrúe explicacións alternativas ás da ciencia pero perfectamente plausibles. Reflexionan que isto pode situar á persoa docente nun dilema pedagóxico, dada a dificultade de fornecer ao alumnado con todas as teorías e probas precisas para explicar certos fenómenos.

Gotwals e Songer (2013) documentan unha progresión de aprendizaxe no desenvolvemento de explicacións baseadas en probas con alumnado de 11-12 anos. O nivel máis baixo nesta progresión implica elixir probas apropiadas para unha determinada conclusión, ou viceversa. Os seis niveis superiores implican responder a unha pregunta científica, retirando progresivamente a andamiaxe do uso de ideas clave e probas. Destes seis niveis, os tres máis altos implican a construción dunha explicación científica que inclúa conclusión, probas e xustificación. Isto denomínase coñécese como o marco CER (Claim, Evidence, Reasoning) de construción de explicacións: formular unha conclusión, usando probas e argumentos para apoiala (Zembal-Saul, McNeill & Hershberger, 2013). Con alumnado de educación primaria, o foco é na coordinación coas probas, e pode incluír tamén a xustificación (ou *reasoning*); e a refutación en niveis máis elevados. Aínda mostrando as dificultades do alumnado ao construír explicacións, Gotwals, Songer e Bullard (2012) apuntan que a capacidade do alumnado de ofrecer explicacións claras e coherentes vese favorecida pola exposición reiterada aos mesmos fenómenos en diferentes contextos.

En canto a como constrúe explicacións o alumnado de educación infantil, hai menos publicacións ao respecto. Sábese que fan uso das súas experiencias cotiás na construción das súas explicacións científicas (Fleer & Pramling, 2015). Siry e Max (2013) documentan como o alumnado de educación infantil constrúe explicacións de certa sofisticación nun currículo mediado polos seus intereses. Leuchter, Saalbach e Hardy (2014) concluíron que as explicacións sobre flotación do alumnado de educación infantil melloraron despois da instrución cun currículo innovador.

En resumo, a construción de explicacións sobre fenómenos científicos implica identificar *que factores* inflúen no fenómeno e *como* inflúen. É importante implementar *curricula* que fornezan aos estudantes con oportunidades para construír explicacións; e andamialos nesta práctica, a fin de que sexan capaces de construír explicacións de maior complexidade. Neste traballo examinamos puntos de entrada (*entry points)* na construción de explicacións por alumnado de educación infantil, atendendo á súa complexidade.

2.3.5 A Observación

Neste apartado discútese a relevancia de aprender a observar desde idades temperás, a importancia da observación na construción do coñecemento científico; e caracterízase a práctica de observación cun propósito.

Winner, Goldstein & Vincent-Lacrin (2014) salientan a importancia que ten aprender a observar desde idades temperás. Para estes autores trátase dunha destreza crítica, importante non só en ciencias experimentais, senón en áreas como as artes ou as ciencias sociais. Ao ensinar a observar a nenas e nenos pequenos, estes son capaces de incorporar o observado e mellorar así as súas creacións, como por exemplo modelos e debuxos. A destreza aprendida para aplicación nun dos campos é extrapolable a outros: cabe destacar que Galileo Galilei tiña formación como debuxante, o cal puido supoñer unha vantaxe ao realizar as súas observacións do ceo. Gelman e Brennemann (2012) destacan que a observación xoga un rol importante na construción do coñecemento científico e inclúena entre as cinco prácticas básicas da ciencia no seu programa *PrePS*. Gelman e Brennemann indican a conveniencia de introducir aos nenas e nenos na observación sistemática. O marco do NRC (2012), nas orientacións sobre o desempeño das prácticas, salienta a importancia da observación das experiencias directas nos graos K-2, aínda que non a diferencia como unha práctica en si mesma. Tampouco a diferencia o marco de PISA (OECD, 2016). Porén, si que forma parte doutras prácticas, especialmente da práctica *3 Planificar e levar a cabo investigacións*

(Duschl & Bybee, 2014).

A observación é unha ferramenta de recollida de datos de primeira man, é dicir, datos recollidos ou xerados polo propio alumnado. Varelas e Pappas (2013) afirman que os datos poden ser recollidos e interpretados tanto no contexto da experimentación como da observación. Hai algúns estudos que comparan o uso de datos de primeira e segunda man. No de Delen & Krajcik (2015), pedíaselle ao alumnado usar datos para a construción de explicacións: encontraron que as mellores explicacións as formulaban ao analizar os datos primarios. Hug e McNeill (2008) encontraron beneficios e limitacións no uso de ambos tipos de datos, polo que indican a conveniencia de combinar ambos.

A observación precisa ser sistemática (Gelman & Brenneman, 2012), activa e ter un propósito, para que resulte produtiva de cara a construción de probas empíricas. O benestar emocional tense revelado como un factor clave na capacidade de observar do alumnado de educación infantil (Klemm & Neuhaus, 2017). Para Alexander (2008) o propósito é unha característica relevante do ensino dialóxico, xa que promove o diálogo dentro de liñas de pensamento e indagación coherentes. A observación durante tempo prolongado ten vantaxes fronte á observación a curto prazo; por exemplo, permite seguir procesos. Ademais, pode ser usada para a revisión e refinamento de ideas. Unha contribución novidosa desta tese, publicada en Monteira e Jiménez-Aleixandre (2016) é a caracterización da *observación cun propósito*: aquela observación prolongada no tempo, sistemática, cun foco determinado, que é discutida e é utilizada para apoiar conclusións e revisar teorías. Este concepto é discutido en profundidade no estudo preliminar que abre a sección de resultados, capítulo 4. A noción de observación cun propósito é usada por Morris (2007) no campo da formación en medicina. Descríbea tendo en conta: a) que o alumnado é invitado a observar; b) o coñecemento previo da actividade de observación; c) o propósito de aprendizaxe que conleva a actividade de observación. Tamén é unha noción ligada á observación como instrumento de investigación (Merriam, 2009), deliberadamente planificada e rexistrada sistematicamente. Propoñemos estender esta idea á observación tanto de seres vivos como de procesos, que o alumnado de educación infantil realiza no curso dos proxectos de ciencia nos que se implican durante esta etapa e que son obxecto desta tese. Suxerimos que a observación cun propósito é unha práctica que facilita a participación noutras, como levar a cabo investigacións e experimentos. Pode usarse para a recollida de datos primarios, que poden ser usados na construción de explicación, e a revisión de modelos.

Existe acordo sobre a importancia da observación na construción do coñecemento científico. Neste estudo, caracterizamos a observación cun propósito (Monteira & Jiménez-Aleixandre, 2016) e documentamos os beneficios que ten para a aprendizaxe as ciencias a implicación do alumnado de educación infantil nesta práctica.

2.4 A SEMIÓTICA SOCIAL DA COMUNICACIÓN VISUAL

Neste apartado discútese a teoría semiótica social da comunicación visual e o seu potencial no estudo dos debuxos infantís.

Segundo Jewitt e Oyama (2008): “Social semiotics of visual communication involves the description of semiotic resources, what can be said and done with images (and other visual means of communication) and how the things people say and do with images can be interpreted” (p. 134). *Recurso semiótico* é un termo clave na semiótica social. Ten a súa orixe na teoría lingüística de Halliday (1978), quen considera a linguaxe como un sistema de escollas e potenciais de significado nun contexto social particular. A semiótica social estende esta idea a outros modos semióticos, como a comunicación visual. Os *recursos semióticos* son medios de produción de significados: son os xestos e artefactos utilizados na comunicación. No contexto da aula, as interaccións discursivas son multimodais: ocorren a través da combinación de diferentes modos semióticos, como comunicación verbal ou visual (xestual, escrita) (Kress, Ogborn & Martins, 1998). A aprendizaxe implica a construción de significados, polo que pode ser considerada como un proceso de produción de *símbolos*, a través do cal os nenos, segundo as súas escollas, "refán" o que o profesor comunica (Jewitt, Kress, Ogborn & Tsatsarelis, 2001). O proceso de produción de símbolos implica facer escollas baseadas en aspectos culturais, históricos, sociais e contextuais (Kress & Van Leeuwen, 1996). O significado dos símbolos varía segundo o grupo social que os produce e comunidades distintas interprétanos dun xeito diferente.

A fin de ampliar a comprensión do rango de significados simbólicos contidos nos debuxos, esta perspectiva permítenos acceder á *gramática visual* utilizada nelas (Kress & Van Leeuwen, 1996). Kress e Van Leeuwen (1996) extrapolan o significado que o termo gramática ten na linguaxe para a súa aplicación en *enunciados* visuais, nos que a colocación e combinación dos elementos que compoñen a imaxe producen significados. Segundo eles, a elección de recursos semióticos, como a disposición dos elementos, divisións e conexións entre eles, ou a súa relación coa persoa que ve a imaxe, está baseada en supostos culturais. Estes supostos están sempre presentes, aínda que non necesariamente de forma explícita, nin sequera para o produtor da imaxe. Así, o potencial de significado depende da comunidade onde a mensaxe visual é producida e recibida.

Kress e Van Leeuwen (1996) describen os recursos semióticos tendo en conta o seu potencial de significado para as culturas occidentais, que comparten trazos culturais importantes, como o uso do alfabeto latino, que implica que a mensaxe é creada (escrita) e recibida (lida) de esquerda a dereita. Segundo estes autores, os recursos semióticos poden ser agrupados en tres categorías, recursos *representacionais*, *interactivos* e *composicionais*, conforme ao seu potencial de significado. Cada categoría inclúe varios tipos de recursos específicos. A Táboa 2. 3 inclúe o potencial de significado dos diferentes tipos de recursos en cada categoría (elaboración propia, adaptada de Kress & Van Leeuwen, 1996). En negriña, destácanse aqueles relevantes nesta tese; entre parénteses, inclúense os termos orixinais usados por Kress e Van Leeuwen (1996), nos casos que, para adaptalos á medida do posible aos datos examinados, a denominación orixinal foi modificada.

Os recursos *representacionais* conteñen á esencia do que é representado e poden ser narrativos, por exemplo imaxes que representan unha acción, como o procedemento dun experimento; ou conceptuais, por exemplo, imaxes que representan unha entidade, como un átomo.

Os recursos *interactivos* suxiren unha interacción entre a imaxe e o receptor desta, como pode ser unha relación de superioridade. Os recursos *composicionais* suxiren relacións entre os elementos da imaxe, por exemplo, pola súa colocación ou coloración relativa, ou polas conexións e desconexións entre eles. Os recursos semióticos descritos por Kress e Van Leeuwen, distribuídos nestas tres categorías de potenciais de significado, foron modificados para adaptalos aos propósitos da investigación, como é discutido en detalle no capítulo 5.

Táboa 2. 3. Tipos de recursos semióticos, agrupados en tres categorías: representacionais, interactivos e composicionais

Categoría	Tipos	Potencial de significado
Representacional	Narrativo	Representa unha acción que ten lugar
	Descritivo (Conceptual)	Representa unha entidade. Por exemplo, unha *estrutura analítica*: representa as partes que compoñen un todo
Interactivo	Contacto	Indica formas nas que a imaxe se relaciona coa persoa que a observa
	Distancia	Suxire diferentes graos de familiaridade da imaxe coa persoa que a observa
	Posición (Punto de vista)	Indica perspectiva entre a imaxe e a persoa que a observa
	Modalidade	Refírese a elección dun modo determinado de representar a realidade. Por exemplo, *científico*
Composicional	**Valor informativo**	A posición relativa dos elementos fornece dunha base para a súa interpretación (pode depender da cultura)
	Encadre	A posición relativa dos elementos suxire conexións ou desconexións entre eles
	Prominencia	Relación de equilibrio ou desequilibrio en talla/colocación/cor. Por exemplo, entre fondo e primeiro plano

A elección de que recursos semióticos usar para comunicar visualmente un significado depende dos intereses da persoa que o constrúe e do que é apropiado para o contexto no que o constrúe.

Neste estudo analizamos os debuxos das nenas e nenos producidos no curso dos proxectos de ciencia. A semiótica social fornécenos dunha perspectiva a partir da cal podemos explorar algúns dos significados construídos polas nenas e nenos nos seus debuxos, que complementan outras análises que levamos a cabo, como a análise de contido (Bell, 2001).

3 METODOLOXÍA

Neste capítulo discútese a metodoloxía empregada na tese en catro apartados. No primeiro abórdanse os obxectivos, desglosados en catro preguntas de investigación. No segundo discútese o enfoque cualitativo, no que se enmarca este traballo, e as estratexias metodolóxicas dos estudos de caso e lonxitudinais. No terceiro caracterízanse o contexto e os participantes. No cuarto discútense os tipos de datos recollidos e os métodos de análise.

3.1 Obxectivos

O obxectivo xeral da tese é examinar como participa o alumnado de educación infantil nas prácticas da ciencia e como a súa participación evoluciona do primeiro ao terceiro curso da etapa, que abrangue dos 3 aos 6 anos de idade.

As prácticas examinadas en profundidade son o uso de probas, o uso e construción de modelos, a construción de explicacións e a observación cun propósito. A decisión de poñer o foco nestas prácticas, débese a que os proxectos de ciencias que levaron a cabo os participantes forneceron máis oportunidades para que nenas e nenos se implicaran nelas. As decisións respecto aos contidos e como se desenvolven os proxectos foron tomadas na súa totalidade polas mestras, xa que o rol da investigadora é de observadora. É dicir, o estudo non é unha intervención, senón que se acompaña as aulas de educación infantil mentres están implicadas en proxectos de ciencias de longa duración.

Este obxectivo pódese desglosar en catro obxectivos xerais de investigación, os tres primeiros sobre o alumnado e un cuarto referido ás estratexias das mestras:

1) Examinar que características ten o uso de probas polo alumnado de educación infantil, como evoluciona ao longo da etapa, e cal é o papel da observación cun propósito neste uso de probas.

2) Examinar que características ten o uso e construción de modelos polo alumnado de educación infantil, como evoluciona esta construción ao longo da etapa, e cal é o papel das representacións nesta práctica.

3) Examinar que características ten a construción de explicacións polo alumnado de terceiro curso de educación infantil e como evoluciona ao longo dun curso escolar.

4) Examinar como apoian as mestras a participación do alumnado nas prácticas científicas e como cambia este apoio (*andamiaxe*) ao longo da etapa.

Dada a natureza dos obxectivos de investigación, o estudo encádrase nunha perspectiva cualitativa, que é discutida a continuación.

3.2 MÉTODOS: UN ESTUDO LONXITUDINAL

De acordo aos nosos obxectivos, o enfoque da investigación é cualitativo, apropiado para coñecer como as persoas interpretan e dan sentido ás súas experiencias, é dicir, cal é o significado dun fenómeno para as persoas implicadas nel (Merriam, 2009). Segundo explica Patton (p. 1, 1985): "[*Qualitative research*] is an effort to understand situations in their uniqueness as part of a particular context and the interactions there".

A investigación cualitativa ten a súa orixe nos eidos da socioloxía e da antropoloxía. No ano 1967, dous sociólogos, Barney Glaser e Anselm Strauss, publicaron *Discovery of Grounded Theory: Strategies for Qualitative Research*, obra que sentou parte importante das bases de posteriores investigacións enmarcadas nesta metodoloxía. Nela discuten a construción de teoría a partir da análise indutiva dos fenómenos sociais. Nas décadas de 1970 e 1980 incrementáronse o número de investigadores e o número de investigacións cualitativas publicadas en revistas específicas de campos, como educación, dereito ou traballo social (Merriam, 2009).

Merriam (2009) sinala que as catro características básicas da metodoloxía cualitativa son: a) que pon o foco no significado e comprensión do proceso; b) que a persoa investigadora é o instrumento primario de recollida e análise de datos; c) que se trata dun proceso indutivo; e d) que o produto resultante posúe unha gran riqueza descritiva. Ademais, o deseño é emerxente e flexible, xa que vai parello aos cambios no estudo que se leva a cabo.

Existen varios enfoques na investigación cualitativa. O seguido nesta investigación é o estudo de caso. Segundo Yin (2003), este enfoque é axeitado cando se estuda un fenómeno contemporáneo nun contexto real, no que os límites entre este e o contexto non están claramente definidos. Este autor apunta que é indicado para examinar que e como ten lugar o fenómeno baixo estudo; e en casos nos que a persoa investigadora ten pouco control sobre a realidade estudada. O deseño inclúe identificar o caso e configurar límites ao mesmo, delimitar "the case as a thing, a single entity, a unit around which there are boundaries" (Merriam, 2009, p. 27). Outros aspectos que destaca Merriam é que neste tipo de estudos, a revisión da literatura forma parte esencial do deseño da investigación e axuda a enfocar a análise. Ademais, indica que toma de datos e análise poden ten lugar simultaneamente. Este tipo de deseño permite realizar un estudo profundamente descritivo. Como limitación, inherente a natureza do estudo, cabe salientar que os resultados non son xeralizables.

Nesta tese lévase a cabo un estudo de caso múltiple en dúas aulas educación infantil do mesmo colexio, cuxas mestras pertencen ao mesmo grupo profesional e seguen a mesma metodoloxía de ensino, co obxectivo de examinar e comparar a súa participación nas prácticas da ciencia en diferentes idades no contexto do mesmo proxecto de ciencias. No que constitúe o estudo central da tese, a unha das aulas acompañámola durante os tres anos da etapa, co propósito de examinar a evolución da participación de nenas e nenos nas prácticas científicas dos 3 aos 6 anos de idade, seguindo un deseño de estudo de caso lonxitudinal (Menard, 2008), apropiado para este obxectivo.

3.3 Participantes e Contexto

O estudo desenvolveuse entre setembro de 2013 e xuño de 2016, en dous grupos do segundo ciclo de educación infantil dun Centro de Educación Infantil e Primaria (CEIP) público, situado nunha cidade de galega de tamaño medio. As linguas vehiculares son o galego e o castelán. O colexio ten 33 mestres, 440 estudantes e o estatus socio-económico das familias é medio.

O deseño implica a inmersión da investigadora nas aulas mentres levan a cabo proxectos de ciencia de longa duración. Informouse á dirección do centro ás familias da finalidade da investigación e do uso dos datos. Ao principio de cada curso escolar, pedíuselle autorización escrita á dirección do centro e aos titores legais do do alumnado, ao tratarse de menores de idade, para acompañar e gravar as aulas. A fin de protexer a identidade dos participantes no estudo, mestras, nenas e nenos de ambos grupos son identificados mediante pseudónimos que respectan o seu xénero e orixe étnica.

No primeiro ano de estudo (curso 2013/2014) acompañouse aos dous grupos e no segundo (2014/2015) e terceiro (2015/2016) ao grupo do estudo lonxitudinal, ECE-L. Esta aula da que a mestra é Mar (pseudónimo), acompañámola ao longo dos tres anos da etapa educativa, de primeiro a terceiro curso do segundo ciclo de educación infantil, dos 3 aos 6 anos de idade. Denominamos os tres cursos ECE1-L, ECE2-L e ECE3-L. Houbo variacións no alumnado: o primeiro curso eran 23 alumnos: 10 nenas e 13 nenos. Deles, un neno e dúas nenas proceden de familias de orixe inmigrante: norte de África e leste de Europa. Todos falan e entenden galego e castelán, as linguas que usan na aula. O segundo curso incorporáronse dous nenos máis ao grupo; e o terceiro curso abandonaron o grupo un neno e unha das nenas cuxa familia é de orixe inmigrante. Ademais, un neno e unha nena que permaneceron durante os tres anos do estudo teñen necesidades educativas especiais. A idade media das nenas e nenos desta aula ao comezo do estudo (setembro 2013) era de 3 anos e 2 meses.

O outro grupo, que chamaremos ECE3-P (preliminar), foi estudado durante o primeiro ano do estudo, en terceiro curso de educación infantil. Sol (pseudónimo) foi mestra (e titora) dese grupo ao longo de toda a etapa, polo que cando o estudo foi realizado, os nenos levaban dous anos traballando con ela, seguindo a mesma metodoloxía, discutida máis abaixo. Son 25 alumnos, 16 nenas e 9 nenos. A familia dun dos nenos procede do norte de África. O neno fala e comprende español e galego. A idade media ao comezo do estudo era de 5 anos e 3 meses.

As mestras destas aulas, Mar e Sol, pertencen a un grupo profesional, formado por seis mestras de educación infantil. Eran as dúas únicas mestras do grupo que impartían docencia no mesmo centro educativo. Cada curso, dende que o grupo se fundou hai 10 anos, as mestras levan a cabo nas súas aulas un proxecto de ciencias, de varios meses de duración. Cunha frecuencia media de dúas veces ao mes, o grupo reúnese para discutir o deseño dos proxectos e compartir o avance destes nas súas respectivas aulas, xuntanzas nas que a autora da tese e a directora participaron. Ao principio do estudo, Mar contaba con 15 anos de experiencia. Sol contaba con 28, sendo unha das dúas mestras con máis experiencia do grupo profesional. Ambas pertencen ao grupo desde a súa fundación, e Sol xa realizaba proxectos de ciencia na súa aula con anterioridade. As mestras do grupo consideran que os nenos posúen capacidades para facer ciencias e que a participación do alumnado en proxectos de ciencia desde a educación infantil fomenta o seu desenvolvemento integral. A súa práctica profesional baséase nos seguintes principios: os proxectos deben partir de situacións que fomenten a motivación e curiosidade do alumnado; a implicación do alumnado no proxecto ha de ser activa; e o desenvolvemento do mesmo ha de ser adaptable aos intereses e preguntas formulados por nenas e nenos. As mestras denominan *sesión de motivación* á primeira sesión de cada proxecto, xa que ten como obxectivo espertar a curiosidade e interese dos nenos polo contido a tratar durante os meses seguintes. Conforme a estes principios didácticos, as mestras guían e acompañan ao alumnado na construción colectiva de coñecemento a través da participación activa nas prácticas da ciencia, en particular:

- formular preguntas
- deseñar e levar a cabo experimentos
- recoller e xerar datos e usalos para apoiar conclusións
- usar e construír modelos
- construír explicacións
- procurar e compartir información

As mestras procuran a implicación das familias nos proxectos que levan a cabo nas aulas. Con frecuencia, os nenos traen de casa información sobre o tema que están tratando, que buscaron coas súas familias, por exemplo, libros, textos, fotos ou diagramas. Os nenos representan as experiencias e os contidos dos proxectos mediante debuxos, que son recollidos polas mestras e encadernados; e o portfolio resultante é entregado ás familias ao final do proxecto.

Os contidos de ciencias escollidos polas mestras para os proxectos dos tres anos que durou a toma de datos foron: caracois (primeiro ciclo de toma de datos), desenvolvemento dos pitiños no ovo (segundo); e nubes (terceiro), como se resume na táboa 3.1. Os contidos e experiencias dos proxectos foron representados polos nenos e nenas mediante debuxos.

Táboa 3.1.Proxectos de ciencias nos grupos participantes no estudo

Grupo	Alumnos (idade)	Mestra	Curso escolar	Proxecto	Duración (meses)
ECE1-L	23 (3-4)	Mar	2013/2014	Caracois	5
ECE2-L	25 (4-5)	Mar	2014/2015	Pitiños	2
ECE3-L	23 (5-6)	Mar	2015/2016	Nubes	5
ECE3-P	25 (5-6)	Sol	2013/2014	Caracois	5

O proxecto ‘Caracois’ desenvolveuse durante cinco meses, de comezos de xaneiro a finais de xuño, e forneceu ao alumnado con oportunidades para responder a cuestións sobre os animais formuladas por eles mesmos; e para apoiar as súas conclusións a partir de datos obtidos mediante observación, experimentación e procura de información. Por esa razón, examinamos a práctica de argumentación en base a probas no contexto deste proxecto. O proxecto do segundo ano, ‘Pitiños’, maioritariamente implicou actividades de observación e representación; e ningunha de experimentación. Desenvolveuse durante dous meses, de xaneiro a marzo, desde a incubación dos ovos até pouco despois do nacemento dos polos. No contexto do proxecto ‘Nubes’, tamén de cinco meses de duración, nenas e nenos tiveron múltiples oportunidades de realizar observacións e deseñar experimentos. Dedicaron gran parte do proxecto á discusión e construción de explicacións sobre os cambios de estado da auga, polo que puxemos o foco da análise nesa práctica. Xa que os proxectos do primeiro e terceiro ano permitiron que nenas e nenos tomaran parte nunha maior diversidade de prácticas científicas, centrámonos nestes dous cursos escolares para a análise da evolución da súa participación nestas. A continuación, preséntase o desenvolvemento de ambos proxectos; e como foron levados a cabo en cada unha das aulas.

O proxecto ‘Caracois’ comezou coa “aparición” dunha caixa con caracois (*Helix aspersa*) na aula. Os nenos identificaron aos animais, xa que se observan con frecuencia na cidade e resultan familiares para eles. Moitos manifestaron coñecer aspectos do seu comportamento e da súa bioloxía. Por exemplo, sabían que comen plantas das hortas, ou que son animais que poden retraer os cornos, ocultándose na cuncha. Motivados pola aparición dos caracois, nenas e nenos compartiron os seus coñecementos e formularon preguntas, que foron rexistradas polas mestras. As primeiras preguntas que xurdiron foron referentes á alimentación, xa que as mestras lles dixeron que deberían coidar deles. Ademais, formularon cuestións referentes aos sentidos, e outras cuestións sobre a bioloxía dos caracois. Tanto en ECE1-L como en ECE3-P, dous alumnos se encargaban, de forma rotatoria, de abrir e limpar a caixa dos caracois todos os días e compartir as súas observacións co resto dos compañeiros. A mestra do grupo ECE1-L, colgou un mural con dúas columnas, unha cunha cara sorrinte e outra cunha cara triste nas que nenas e nenos pegaron fotos da comida que o caracol comía ou deixaba intacta, respectivamente. A mestra do grupo ECE3-P, rexistrou as preguntas dos nenos nun mural con tres columnas: “que sabemos”, “que queremos saber” e “que aprendemos”, que foron completadas no transcurso do proxecto. Moitas das preguntas dos nenos foron similares en ambas aulas, por exemplo as referentes aos sentidos, e as que eran distintas eran compartidas polas mestras dos demais grupos.

Para responder ás cuestións de se os caracois tiñan sentido do olfacto, do ouvido e do gusto, levaron a cabo tres experimentos. A estratexia das mestras e a súa dirección deu lugar a que os experimentos propostos polo alumnado foran, en moitos casos, iguais ou similares. Ilustramos este punto cun exemplo: o experimento deseñado para comprobar se os caracois posuían sentido do olfacto. En ambas aulas xurdiu esa cuestión, e o alumnado, andamiado pola mestra, propuxo comprobar o comportamento dos animais fronte a substancias con e sen cheiro perceptible. As substancias que as mestras levaron ás aulas foron vinagre e auga, e comprobaron que os caracois daban a volta ao chegar ao vinagre e, porén, achegábanse á auga. Ademais dos experimentos, as mestras compartiron outras informacións que aportaron riqueza ao desenvolvemento do proxecto e foron levadas ás súas respectivas aulas. Por exemplo, todas as mestras andamiaron as observacións dos nenos ao longo do tempo, un tipo de práctica que denominamos *observación cun propósito* (Monteira & Jiménez-Aleixandre, 2016) e que é discutida no capítulo 4 de resultados. Dese xeito, os nenos obtiveron datos a partires dos que foron capaces de extraer conclusións, por exemplo as relativas á relación entre a cor dos excrementos e a cor da comida inxerida. Houbo cuestións que só xurdiron nalgunha das aulas. Por exemplo, en ECE3-P, rompeu a cuncha dun caracol, co cal, mediante observación cun propósito, puideron responder á cuestión de se esta se rexeneraba ou non.

O proxecto ‘Nubes’ comezou coa “aparición” dunhas fotos de nubes nas paredes da aula de ECE1-L. Os nenos recoñecéronas como tales e comezaron a discutir a súa formación, orixe e características. Igual que cos caracois, os nenos están moi familiarizados coas nubes, xa que a escola sitúase nunha das cidades máis chuviosas do país. Ao longo do proxecto trataron contidos como a formación e tipos de nubes, os fenómenos atmosféricos, o ciclo da auga e os cambios de estado. Nas primeiras sesións, aceptaron a idea de que as nubes estaban feitas de auga, proposta por dous compañeiros. Porén, non sabían *como* a auga podía chegar ás nubes. Andamiados pola mestra, os nenos realizaron catro experimentos que implicaron cambios de estado líquido-gas en condicións diferentes e estudaron o ciclo da auga. Realizaron observación de nubes no patio do colexio, para o que empregaron un instrumento que denominaron ‘Nuboscopio’. Ademais, usaron e construíron modelos, en diversos modos semióticos, de nubes e de cambios de estado.

3.4 ANÁLISE

Neste apartado discútense os tipos de datos recollidos e as análises levadas a cabo. As ferramentas de análise serán discutidas en profundidade nos correspondentes capítulos de resultados.

3.4.1 Recollida de Datos

Na investigación cualitativa existen varios tipos de estratexias de recollida de datos, sendo os relevantes para o noso estudo: a observación participante, a análise do discurso, a análise documental e as entrevistas coas mestras.

En canto á primeira, aínda que intención era realizar unha observación sen participar no transcurso das sesións, a presencia da investigadora foi usada con frecuencia polas mestras como un estímulo para que o alumnado lle explicara cuestións relativas aos contidos dos proxectos. Experimentar a realidade baixo estudo conxuntamente cos participantes implica vantaxes e retos. Por unha banda, axuda a evitar distorsións na interpretación; por outra banda, fai preciso un esforzo para tomar unha distancia con respecto aos datos para levar a cabo unha análise sistemática. Durante o primeiro ano de estudo, debido tanto a que houbo observacións que xurdiron de forma inesperada, como a que os proxectos desenvólvense de forma case continua, en parte de moitas sesións, e a que as mestras tiñan dificultades para distinguir que sesións eran de interese e advertir a investigadora, non se acompañou a totalidade das sesións de proxecto, polo que parte dos contidos tratados e actividades realizadas coñecémolas indirectamente, a través das explicacións e debuxos dos nenos e mediante entrevistas informais cos mestras. A partires do segundo ano acompañamos á aula en tódalas sesións nas que traballaron contidos de ciencias relacionados cos proxectos.

Os datos recollidos abranguen distintos tipos, o que permite a contrastación: graváronse en vídeo as sesións, recolléronse as producións do alumnado e tomáronse notas de campo. Pediuse autorización por escrito á dirección do centro e ás familias do alumnado para acompañar e gravar as sesións. Ademais, antes e durante a implementación de cada proxecto, asistiuse a reunións co grupo de mestras. As reunións previas dedicáronse á toma de decisións, por parte das mestras, acerca dos contidos e deseño do proxecto. A investigadora, a directora da tese, e outros membros do equipo de investigación proporcionaron formación sobre aspectos específicos relacionados con contidos de ciencias, a demanda do grupo de mestras. Durante o transcurso do proxecto, as mestras compartiron información sobre o desenvolvemento do mesmo nas súas respectivas aulas. Tamén foron atendidas necesidades específicas das mestras, por exemplo, en canto ao uso dos instrumentos empregados por elas nos proxectos, como o estereomicroscopio ou a incubadora, ou cuestións relacionadas cos contidos científicos, non tratadas previamente, e xurdidas a partir de preguntas dos nenos.

Os tipos de datos analizados en profundidade son as transcricións das sesións de aula, mediante análise de discurso; e os debuxos do alumnado, combinando varios métodos de análise de documentos visuais. O foco neste tipo de datos débese a dúas razóns de diferente natureza: por unha banda, como xa se indicou no marco teórico, as interaccións discursivas e as representacións (debuxos) teñen un rol destacado na construción do coñecemento (e.g. Bruner, 1996; Fleer & Pramling, 2015). Por outra banda, seguindo os principios da investigación cualitativa e, particularmente, do deseño escollido, o estudo de caso, os métodos de análise adáptanse á realidade baixo estudo; e consideramos que, debido á súa frecuencia e á súa natureza, ambos tipos de datos son relevantes nesta aulas para examinar os significados creados polos participantes no estudo. A Táboa 3.2 resume os datos recollidos durante o primeiro e terceiro ano de estudo. Debido a que as ausencias en educación infantil son frecuentes, non todos os alumnos entregaron todos os debuxos.

Táboa 3.2. Recollida de datos

Grupo	Sesións gravadas (hh:mm)	Debuxos (nº tarefas)
ECE1-L	6 (3:05)	353 (18)
ECE3-L	24 (27:22)	178 (9)
ECE3-P	6 (5:05)	149 (7)

3.4.2 Análise do Discurso

A análise do discurso emprégase para estudar o significado da linguaxe en uso (Gee, 2005). A unidade de análise que empregamos é o turno, definido como cada intervención dos participantes na conversa. Coa finalidade de construír un mapa de eventos para cada sesión, os turnos foron agrupados en episodios, definidos, seguindo a Gee, como ou varios turnos relacionados co mesmo tema ou coa mesma acción.

Mediante a interacción dos datos e a literatura, identificáronse compoñentes da conversa argumentativa (Jiménez-Aleixandre & Erduran, 2008); das explicacións (McNeill, 2011); e de modelización (Schwarz et al., 2009). A partir da identificación destes elementos, desenvolvéronse rúbricas de análise da participación nestas tres prácticas en educación infantil, como se discute nos capítulos de resultados.

En interacción coa literatura sobre andamiaxe (Van de Pol et al., 2010), identificáronse as estratexias de andamiaxe verbal empregadas polas mestras para apoiar a participación do alumnado nas prácticas, que foron codificadas, segundo se discute no último capítulo de resultados. Ademais, leváronse a cabo análises de contido das transcricións para a identificación dos temas recorrentes ao longo das sesións.

3.4.3 Análise de Datos Visuais

Existen diferentes métodos de análise de datos visuais que permiten examinar os debuxos dos nenos e nenas. Para escoller un ou outro, consideramos a natureza do noso conxunto de datos e o que queriamos aprender del. Temos en conta:

a) De que tipo son os debuxos? no noso caso, representacións de contidos científicos.

b) Quen son os produtores? e as relacións entre eles; son nenos e nenas na aula de educación infantil.

c) O contexto en que foron producidos; pedíuselles ao alumnado que elaborase os debuxos no contexto dun proxecto científico escolar.

d) O foco da análise, no noso caso o propio produto, o debuxo, máis que o proceso de produción.

Nesta sección discútense as dúas análises visuais que realizamos, (1) a análise comparativa do contido e (2), a análise semiótica social, xustificando por que se elixiron para esta investigación. Estas dúas análises poden considerarse complementarias, xa que permiten acceder á información dos debuxos desde diferentes perspectivas. A análise comparativa de contido céntrase no *que* se representa, mentres a semiótica social céntrase en *como* se representa.

Por unha banda, a *análise comparativa do contido* (Bell, 2001), úsase para examinar mostras de contido comparable. Permite estudar e cuantificar produtos visuais, verbais, orais e gráficos utilizando categorías explicitamente definidas (Bell, 2001). Para estudar e cuantificar categorías de contido, é necesario definir *variables* e *valores*. Unha variable de contido consiste en calquera dimensión ou intervalo de opción. Unha variable pode ter valores diferentes, que son elementos que pertencen á mesma clase. Usamos este tipo de análise para examinar que elementos hai nos debuxos, tanto introducidos polos nenos, como pola mestras como andamiaxe estrutural das tarefas de debuxo. Tamén a empregamos para examinar cambios en tarefas de representación comparables repetidas ao cabo dun intervalo de tempo.

A perspectiva de análise semiótica social (Kress & Van Leeuwen, 1996), discutida no marco teórico, aporta información sobre o potencial de significado creado por *como* os contidos dos debuxos son representados. Analizamos desde esta perspectiva debuxos que non sufriron ningunha modificación *a posteriori* por parte da mestra. Este punto é de gran importancia, dado que a intervención implica unha modificación no potencial de significado do debuxo, que é ao que queremos acceder. Esta análise é empregada para analizar unha serie de debuxos feitos polo alumnado do grupo ECE1-L no seu primeiro ano de escolarización, co obxectivo de examinar como nenas e nenos se apropian de e usan significados e recursos comunicativos nos seus debuxos mediante a enculturación na comunidade da aula. Xa que a comunicación verbal nesa franxa de idade (3 - 4 anos) é máis limitada que en cursos superiores, os debuxos permiten acceder a parte dos significados que nenas e nenos están construíndo e que doutro xeito sería moi difícil examinar.

II. RESULTADOS

4 THE PRACTICE OF USING EVIDENCE IN EARLY CHILDHOOD: THE ROLE OF PURPOSEFUL OBSERVATION

Findings related to the first research objective, *To explore the features of Early Childhood Education children's engagement in using evidence and what is the role of purposeful observation in this practice,* are discussed in this chapter. Part of the results, regarding only the ECE3-P group, have been published in Monteira & Jiménez-Aleixandre (2016). In this chapter, data from ECE3-P are compared to those from ECE1-L.

4.1 Introduction

We examine the ways in which young children engage in the scientific practice of generating and using evidence to support claims and answer to questions, in the first (ECE1-L, 3-4 year-olds) and third (ECE3-P, 5-6 year-olds) school year of Early Childhood Education (ECE).

Performances at different groups in one school, engaged in the same science project about snails, are compared. In this sense, this part of the study differs from others, in which we explore evolution in the engagement in the practices within the same class (ECE1-L). In order to address the research objective, this was further expanded into the following research questions:

1) In which ways do children in early childhood use evidence and how is this use reflected in the development of data into evidence? What are the differences in the use of evidence between first and third year of ECE?

2) Which ways of gathering empirical evidence are jointly constructed by children and their teachers during the project? Which is the role of observation in this context and which are its features? What are the differences in gathering evidence between first and third year of ECE?

3) How do children use evidence to revise their understandings? What are the differences between first and third year of ECE in the revision of understandings under the light of new evidence?

We first introduce the participants and context, second the data corpus, the analysis methods and tools developed. Then, results are discussed.

4.2 PARTICIPANTS AND CONTEXT

The participants are two ECE classrooms and their teachers. As discussed in chapter 3, in Spain, ECE is part of public school system and children enter school when they are 3 years old and usually remain with the same teacher during all the stage, until they are 5-6. We accompanied both classrooms along the school year 2013-2014, while they were engaged in a five months project about snails.

In ECE1-L, the group that was studied during the three years, and whose teacher is Mar, there are 23 children: 10 girls and 13 boys. Their mean age at the beginning of school year was 3 years and 2 months. Three of them come from families with immigrant origin: northern Africa and Eastern Europe. All of them speak and understand Galician and Spanish, the languages of instruction. There are two children with special educational needs.

In ECE3-P, there are 25 children, 16 girls and 9 boys. Sol has been their teacher since they entered school, so they are used to work in long-term projects. Their mean age at the beginning of school year was 5 years and 3 months. One child comes from a family of immigrant origin. All children speak and understand Galician and Spanish. Children are identified with pseudonyms, respecting gender and ethnical origin.

Sol is one of the two more experienced members of the professional group of six ECE teachers she and Mar belong to, having taught for 28 years by the time of the study; and Mar had taught for 15 years. This is not an intervention study, as the teachers are responsible for the design of the project. The teachers are identified with pseudonyms.

The 'Snails project' in which these two classrooms were engaged has a flexible design, and was modified depending on children's questions and interests. It is framed in design principles parallel to Metz's (2011) principles for science in early primary, here reworded to fit the context of the study.

– *Engagement in practices triggered by curiosity and question-based*: curiosity as the motor that interests children in science. Children's questions are driving the project.

– *Deep prolonged immersion in a problem*: the snails project spans five months, from mid-January to mid-June.

– *Rich domain knowledge entwined with building-knowledge practices*: biology issues explored during the project included the fact that snails are hermaphrodite, their body plan and their mouthparts (radula).

The teachers' approach in their own words involves: 1) *Motivating, eliciting children's interest*: introducing the phenomenon or living being to the class. In this project, bringing a box with garden snails (the big European snail *Helix aspersa*, reaching a length of 28–35 mm); 2) *Collecting children's ideas and producing questions*: producing responses to three questions, used for driving the project, a) what do we know about snails? b) What do we want to know about snails? c) What did we learn? and 3) *Engaging children in scientific practices guided by the teachers*: the children's own questions are the starting point.

The children are familiar with snails. The school is located in a small city with no clear limits with the countryside and many houses have gardens where snails are abundant (and a pest). They do know, for instance, that snails eat greens such as cabbage or collard leaves or that they can withdraw into their shells. Everyday routine included counting up snails and checking what they had eaten. Each day, a team of two children was in charge of cleaning up the terrarium and wetting the snails, so they would come out of their shells. The participation in the project along a sustained period of time created opportunities for a range of experiments and experiences, as well as for children's productions. The children were asked to produce drawings of the experiences and phenomena they engaged with.

Timelines in Table 4.1 and 4.2, summarize the development of the project in both groups. ECE1-L and ECE3-P, respectively, in terms of experiences and observations, topics of classroom talk and children's products, either individual ones, such as drawings, or collective, such as classroom displays. Attendance in ECE is not compulsory, as a consequence, it was not always constant and some children did not attend all the sessions, and did not hand all the productions, which accounts for the differences in numbers.

The project was organized around driving questions suggested by children and the teachers collected them. Formulating empirically answerable questions about phenomena is a basic scientific practice (NRC, 2012; OECD, 2016). It should be noted that many experiences and observations and all the experiments are similar in both classrooms. This is because some of the questions emerged spontaneously in both classrooms, whilst others were shared between the teachers because of its interest, who fostered children's curiosity about the phenomena. For instance, children in both classrooms observed the marks that snails left in the food. The teachers paid attention to these observations and prompted children to talk about it. As a consequence, an investigation about snails' mouthparts emerged in both classrooms.

Regarding the experiments, two of them may illustrate the children's engagement with the project: in experiment 'Hearing' (Figure 4.1), they placed four snails on a lid, and stayed in silence for a few minutes. Then they made noises by a) shouting, b) banging two sticks, and c) playing a tambourine. The snails' behavior in the conditions of silence and noise were compared. Another experiment, 'Strength' (Figure 4.2), tested if snails would be able to pull different objects such as a potato or a paper clip, either through a plastic strainer or through a cardboard "cart" attached to the snail's shell.

Figure 4.1. Children carrying out experiment ‘Hearing’

Figure 4.2. Children carrying out experiment ‘Strength’

Table 4.1 Timeline of the 'Snails project' in ECE1-L

Month	Experiences	Topics of classroom talk in videotaped sessions	Children's products
January	Introducing snails Experiments: 'Smell' and 'Hearing'		1 Classroom display: registering which food snails eat and which is left 23 Snails' initial drawings 20 Drawings experiment 'Smell' 20 Drawings experiment 'Hearing'
February	Experiment 'Taste' Observations: a) Snails' tooth marks on food b) Color of "poo" related to food c) Giving flour to snails to see the radula	*Videotaped session 1*: Discuss colored "poo" and its relation to food's color Report: little holes in the food, radula, "teeth"; snails are mollusks; experiments 'Smell' and 'Hearing' Use snail's inner organs plan to prove it has heart; point to heart's position in real snail Observing snails Drawing a snail (2nd drawing)	20 Drawings colored "poo" 21 Drawings experiment 'Taste' 18 Snails' second drawings
March	Experiment 'Surfaces' Observation: snails' tooth marks on food	*Videotaped session 2*: Discuss: a potato grew in the snail's box. Parts of the plant Discuss: Experiment 'Surfaces' Observing snails: a) with magnifying glass; b) with stereomicroscope (in screen) Drawing snail's parts	20 Drawings experiment 'Surfaces' 18 drawings snail's radula 20 drawings book 'The biggest house' 20 drawings snail's parts 20 drawings film 'Turbo' 20 drawings hermaphrodite
April	Experiments: 'Strength' and 'Balance'	*Videotaped session 3*: Snails are hermaphrodites Snails' race: how to make them advance in straight line	19 drawings stereomicroscope 18 drawings land/sea snails

		Drawing snails' race *Videotaped session 4*: Observing baby snails Parts of snail; snails grew because they ate Experiment 'Balance' Discuss a drawing of the inner parts of snail Observing sea and land shells	22 drawings experiment 'Strength'
May	Observation with e-amplifying lens of a limpet's radula	*Videotaped session 5*: Observing limpet's radula with stereomicroscope: shape, color, "toothlets" *Videotaped session 6*: Discuss: pictures of radula. Mimics and explanations: how snails use the radula Drawing radula	22 drawings experiment 'Balance' 22 drawings limpets' radula
June	Bringing back snails to the garden		19 drawings snails' enemies

Table 4.2. Timeline of the 'Snails project' in ECE3-P (Monteira & Jiménez-Aleixandre, 2016, adapted)

Month	Experiences	Topics of classroom talk in videotaped sessions	Children's products
January	Introducing snails Experiment 'Smell'		3 Classroom displays: a) driving questions; b) what do snails eat; c) hypotheses experiment 'Smell' 23 Snails' initial drawings 6 Modeling clay models 22 Drawings of experiment 'Smell'
February	Experiments 'Taste' and 'Hearing' Observations: a) Snails'	Videotaped session 1: Snails are hermaphrodite Snails' shell grows as snails are growing Broken shell and healing Experiment 'Hearing': data, claims	2 Classroom displays: hypotheses for the experiments 'Taste' and 'Hearing' 20 Drawings mouthparts 23 Drawings of experiment 'Taste'

	healing from salt b) Broken shell recovery c) Color of “poo” related to food	Colored “poo” First ideas about mouthparts Meaning of hypotheses	23 Drawings of experiment ‘Hearing’
March	Experiment ‘Surfaces’ Observations: a) Snails’ tooth marks on food b) Watching a video of snails’ mouthparts c) Giving flour to snails to see the radula	Videotaped session 2: Report: collected information Snails’ “tongue”, radula Snails’ internal organs Experiment ‘Surfaces’: data, claims Videotaped session 3: Snails are mollusks Snails’ “tongue”, “teeth” New question: Why do little snails disappear from the box Revising 20 previous drawings of mouthparts	1 Classroom display: hypotheses experiment ‘Surfaces’ 23 Drawings experiment ‘Surfaces’
April	Weighing snails with scales Using spring & digital scales	Videotaped session 4: Snails’ weight, mucus Problem of scale’s sensitivity Making predictions	
May	Experiments ‘Strength’ and ‘Balance’ Observation with e-amplifying lens of a limpet’s radula	Videotaped session 5: Experiments ‘Strength’ and ‘Balance’: predictions, data, claims Functions of slime Videotaped session 6: Comparison of limpet’ s radula with their ideas of snails’ mouthparts Explanation for how snails use the radula	2 Classroom displays: hypotheses for experiments ‘Strength’ and ‘Balance’ 19 Drawings of experiment ‘Strength’ 20 Drawings of experiment ‘Balance’
June	Bringing back snails to the garden		

4.3 DATA ANALYSIS

In this section, the data corpus and the tools developed for analysis are presented.

4.3.1 Data Corpus

The data analyzed correspond to the data corpus of the first year of the study. Selected sessions were recorded and transcribed and children's drawings were collected, as summarized in Table 4.3. Data analyzed are transcripts of the sessions and children's drawings. Analysis tools are discussed below. It should be noted that during the first year of the study, only selected sessions were recorded, so, along this chapter, we use the term "session N*"* to refer to the N-th recorded session, not to the N-th session of the snails' project.

Table 4.3. Data corpus

Class	N children (years-old)	Sessions recorded (hh:mm)	Drawings collected (different tasks)
ECE1-L	23 (3-4)	6 (3:00)	353 (18)
ECE3-P	25 (5-6)	6 (5:05)	149 (7)

4.3.2 Methods and Tools for the Analysis of the Transcripts

In order to answer research questions 1, *In which ways do children in early childhood use evidence and how is this use reflected in the development of data into evidence? What are the differences in the use of evidence between first and third year of ECE?*, the transcripts were analyzed through prolonged immersion in the data. Excerpts of the transcripts in original language are included along the chapter, following translations. Children in this classroom use two languages, Galician and Spanish, often switching between both in the same sentence. These changes are not marked in the transcript; only the words that do not exist in any of the languages are marked with italics.

Coding categories (Table 4.4) emerged from the interaction of dimensions from argumentation literature (Aikenhead, 2005; Duschl, 2008; McNeill & Krajcik, 2008) with data in successive iterations. These coding categories were developed for the analysis of data from ECE3-P, which is published in Monteira and Jiménez-Aleixandre (2016). The first level of analyses focuses on the identification of argument components: claim—evidence—justification (named reasoning by some authors, e.g. McNeill, 2011).

In this coding scheme, we also included a new category that we developed for the analysis of argumentation in early years: *raw data*. Raw data is defined as description of first-hand observation, experiment or second-hand information, but unrelated to a claim or to a question. We believe it is relevant to distinguish between these descriptions and data that constitute evidence.

Table 4.4. Argumentation coding scheme. Below, excerpts in original language

Code	Description	Student's examples
Claim	A statement or conclusion that answers the original question	"They [*snails' shells*] do not look the same"[1] (ECE1-L) "If a snail grows its shell does grow with it"[2] (ECE3-P)
Raw data	Description of first-hand observation, experiment or second-hand information unrelated to a claim or question	"They [*snails*] are awakening"[3] (ECE1-L) "[*Baby snails are*] very soft"[4] (ECE3-P)
Evidence	Data used to support a claim, judged as significant ("count" for evaluating the claim), and appropriate	"And also the red poo"[5] (evidence used to support "snails ate that [*red blanket*]"[6]) (ECE1-L) "All of them can lay eggs"[7] (no distinction female/male; supporting the claim "[*snails*] are hermaphrodite"[8]) (ECE3-P)
Justification (reasoning)	Connects the evidence to the claim	"[*Because slime*] helps it [*snail*] to walk"[9] (ECE1-L) "... they [*snails*] did not hide. And if they do hide it is because they hear, but they did not hide"[10] (ECE3-P)

Original language:
[1] "[*As cunchas dos caracois*] non son iguais"
[2] "Se un caracol crece su concha si que crece con el"
[3] "[*Os caracois*] están despertando"
[4] "[*Os caracois pequenos son*] moi blandos!"
[5] "Y también la caca roja, eso"
[6] "Que [*os caracois*] comieron eso [*a manta vermella*]"
[7] "[*Os caracois*] pueden poner todos ovos"
[8] "[*Os caracois*] son hermafroditas"
[9] "[*Porque la baba*] le ayuda [*ao caracol*] a camiñar"
[10] "…eles [*caracois*] non se escondían. E se se esconden es que escuchan, pero no se escondieron"

In the context of ECE, we define evidence as data whose discursive role is to support a claim, in other words, which "count as" evidence in the students' discourse, and are appropriate. We do not include McNeill and Krajcik's (2008) "sufficient" condition in our coding scheme, as it seems to be more difficult than appropriateness, even for primary students. For instance, in Gotwals et al. (2012) practice progression for fourth to sixth grades, levels 1 and 2 are defined by the use of "appropriate but insufficient (partial) evidence" (p.187). For the purposes of identifying entry points for the use of evidence in kindergarten, we suggest leaving out sufficiency. Table 4.4 presents the specific codes for argument components, illustrated with examples from children's talk both from ECE1-L and ECE3-P. Below, there are the excerpts of children's talk in original language. Repetitions, which are frequent at this age, such as repeating the piece of evidence another child has offered, were not counted; in other words, we considered each different element only once in each argumentative episode, although they were counted when occurring in a different episode or session.

In a second level of analysis, we coded evidence statements and classified them according to their level of sophistication. The coding scheme, also discussed in Monteira and Jiménez-Aleixandre (2016) draws from Aikenhead (2005) and from Duschl's (2008) first critical transformation in the E-E continuum. In order to illustrate the main points of the E-E continuum approach, that guides our coding scheme for argumentation in early years, an excerpt from Duschl's (2008), is reproduced below:

> E-E focus is on engaging learners in conversations examining "science-in-the-making" practices (Kelly, Chen, & Crawford, 1998). (…) learning mediations should focus on promoting talk, activity structures, signs and symbol systems, or collectively what I will call conversations. For science learning, the conversations should mediate the transitions from evidence to explanations, or vice versa, and thereby unfold discovery and inquiry. The E-E continuum recognizes (…) how cognitive structures and social practices guide judgments about scientific data texts. It does so by formatting into the instructional sequence select junctures of reasoning, for example, data texts

transformations. At each of these junctures or transformations, instruction pauses to allow students to make and report judgments. Then students are encouraged to engage in rhetoric–argument, representation–communication and modeling–theorizing practices. The critical transformations or judgments in the E-E continuum include:

1. Selecting or generating data to become evidence,
2. Using evidence to ascertain patterns of evidence and models, and
3. Employing the models and patterns to propose explanations." (Duschl, 2008, pp. 279-280)

Table 4.5. Evidence coding scheme for ECE

Code	Description	Children examples
Level 1	Descriptive evidence statements closer to data	"[*Snails have*] heart, brain"[1] (claim: "It is almost like us" [2]) ECE3-P
Level 2	Evidence statements involving evaluative judgments, meeting one of these criteria: a) identifying patterns in data	"Poo of the color of what they eat" [3] (ECE3-P)
	b) connecting data and claim through justification;	"[*The snail is going to stay on the wire*] because it has got slime [*Because*] it [*the slime*] helps it [*the snail*] to walk!" [4] (ECE1-L) "If it is not rough it doesn't, doesn't... scrape" [5] (ECE3-P)
	c) establishing comparison with other data;	"And they [*snails*] went back" [6] (Claim: "[*Snails*] they do not like vinegar" [7], implicit comparison of behavior in front of water/in front of vinegar) (ECE1-L) "It [*the snail*] does not eat bit after bit,(...) it makes little holes" [8] (ECE3-P)
	d) explicitly evaluating one or several alternative claims	"No, [*they are snails, not excrements*], they have little horns"[9] (ECE3-P)

Original language:
[1] "Ten corazón, *celebro*..."
[2] "Casi é coma nós"

[3] "[*Los caracoles hacen*] caca del color de lo que comieron"
[4] "Porque tiene baba (…) Le ayuda a camiñar!"
[5] "Tiene que ser rugoso para que a raspen, porque si no es rugoso no, no, no… no raspa..."
[6] "E ademais daban a volta!"
[7] "O vinagre non lles gusta!"
[8] "[*o caracol*] non come trozo a trozo, fai *abuxeriños*"
[9] "Non, [*son caracois, non cacas*], que ten corniños".

In our coding scheme, level 1 are evidence statements closer to data; level 2, evaluative judgments meeting one of these criteria: (a) identifying patterns in data; (b) connecting data and claim through justification; (c) establishing comparison with other data; (d) explicitly evaluating one or several alternative claims. It needs to be noted that although for analytic purposes we distinguish two levels, these should be seen as part of a continuum. Table 4.5 presents the levels with examples from the classrooms. Children's talk in original language is reproduced below. It should be noted that for ECE1-L we did not find any evidence statement meeting criteria *a* or *d*, so Table 4. 5 does not include examples from ECE1-L for these categories. The differences between ECE1-L and ECE3-P are discussed in the first results section of this chapter.

For answering the research question 2, *Which ways of gathering empirical evidence are jointly constructed by children and their teachers during the project? Which is the role of observation in this context and which are its features? What are the differences in gathering evidence between first and third year of ECE?*, the analysis draws on the literature about first and second-hand data (e.g. Hug & McNeill, 2008), and about the relevance of observation, discussed in the theoretical framework, chapter 2. An emergent notion, based on our data analysis is *purposeful observation* (PO), a type of observation that is prolonged, systematic and with a clear focus (Monteira & Jiménez-Aleixandre, 2016), from other types of observation. The coding scheme distinguishes three ways of gathering or generating data:

(1) Empirical first-hand data gathered through purposeful observation
(2) Empirical first-hand data gathered through experiments

(3) Second-hand data found on the Internet, books, or from families.

For answering the research question 3, *How do children use evidence to revise their understandings? What are the differences between first and third year of ECE in the revision of understandings under the light of new evidence?,* the transcripts of the sessions and children's drawings were examined. We carried out a thematic analysis of the transcripts in order to identify recurrent topics. The successive revisions of initial ideas, and the evidence used to change it were identified.

4.3.3 Methods and Tools for the Analysis of Children's Drawings

In order to answer the research question 1, *In which ways do children in early childhood use evidence and how is this use reflected in the development of data into evidence? What are the differences in the use of evidence between first and third year of ECE?* drawings of experiments 'Smell', 'Hearing', 'Taste', 'Strength' and 'Balance' were examined. These drawings were selected because they share a common structure: they represent either the procedure or the conclusions of the experiments carried out by children; and they contain a written claim derived from the experiments. The focus was on the use of argumentative connectors in the written texts within the drawings of experiments, under the printed heading "conclusions". Argumentative connectors are defined by Ducrot (1983) as signs that link two or several statements, assigning them a particular role in the argumentative discourse. In this case, the use of the connector *because* to link evidence and conclusions. The number of drawings examined is 110. Only drawings from ECE3-P were subjected to this analysis, as the sentences that make up the conclusion were decided and written by children, whereas children in ECE1-L were given word tags and asked to paste them in order to build the conclusion sentence. An in-depth analysis of these drawings from ECE1-L is carried out in chapter 5.

In order to answer the research question 3, *How do children use evidence to revise their understandings? What are the differences* *between first and third year of ECE in the revision of understandings under the light of new evidence?,* drawings that represent children's ideas about snails' mouthparts and mollusks' radula at different points of the project were examined through content analysis (Bell, 2001). These are 81 drawings from ECE1-L, corresponding to four different drawing tasks; and 20 drawings from ECE3-P, one drawing task. It should be noted that there is a greater number of drawings examined in ECE1-L than in ECE3-P, as they were asked to produce more drawings regarding this topic.

Table 4. 6. Drawings analyzed in chronological order of production

Group	Drawings of experiments (no. drawings)	Drawings about mouthparts and radula (no. drawings)
ECE1-L	(Not examined for this analysis)	- First drawing of snail (23) - Second drawing of snail (18) - Snail's radula (18) - Limpet's radula (22)
ECE3-P	- Experiment 'Smell' (22) - Experiment 'Taste' (23) - Experiment 'Hearing' (23) - Experiment 'Surfaces' (23) - Experiment 'Strength' (19)	- Snail's mouthparts (20)

4.4 RESULTS: USE OF EVIDENCE IN EARLY CHILDHOOD EDUCATION AND THE DEVELOPMENT OF DATA INTO EVIDENCE

In this section we address research questions1, *In which ways do children in early childhood use evidence and how is this use reflected in the development of data into evidence? What are the differences in the use of evidence between first and third year of ECE?* A summary of results may be that 3 to 6 year-olds are able to engage in the practice of using and generating evidence to support their claims and to answer questions, although with different degrees of complexity. We begin by describing quantitative data, and then discuss the qualitative findings based on discourse analysis.

The quantitative analysis of the transcripts is summarized in Table 4.7. It shows the occurrence of argumentative components in classroom discourse. These data give a sense of the relevance of this type of science talk in the classrooms while generating scientific knowledge.

For ECE1-L, 285 argumentative components were identified, from which 204 are claims. It can be observed that there are more claims than evidence statements (44) used to support them. From these evidence statements, 33 were codified as level 1 and 11 as level 2. There are 37 raw data identified: these are data included in children's talk, but whose discursive role was not that of supporting a claim nor were related to a question. For ECE3-P, more claims (125) than evidence statements (57) were also identified. In other words, similarly to what was found in previous studies with students in higher educative levels (e.g. Jiménez-Aleixandre et al., 2000), most claims are not supported by evidence. From the 57 evidence statements in ECE3-P, 36 were codified as level 1 and 21 as level 2. Not all data are developed into evidence, as shown by 85 of the statements coded under raw data.

Table 4. 7. Argument components in ECE1-L and ECE3-P

Class (turns)	Argument components	Claim	Raw data	Evidence	Justification
ECE1-L (1416)	N= 285	204 (71.58%)	37 (12.98%)	44 (15.44%) Level 1: 33 Level 2: 11	2 (0.7%)
ECE3-P (937)	N = 276	125 (45.3%)	85 (30.8%)	57 (20.6%) Level 1: 36 Level 2: 21	9 (3.3%)

Regarding the differences between the two classes, argumentative components of children's discourse represent a smaller fraction of the total turns in ECE1-L (285/1416; 20.12%) than in ECE3-P (237/937; 25.29%). This is due, on the one hand, to the higher degree of intervention of the teacher in the classroom talk, in order to support children's discussion (directing the focus, questioning children). On the other hand, repeating other child's words is more frequent in first year; and repetitions were not counted unless they took place in a different episode. There is a higher proportion of claims in ECE1-L (71.58%) than in ECE3-P (45.3%), and a lower number of evidence statements used to support them (15.44% and 20.6%, respectively). Most of evidence statements in both classrooms were coded as level 1, in many cases supporting claims related to snails' features, such as color, size, or categories; for instance, snails are mollusks. Epistemic judgments involving evidence evaluation become more frequent with age and educational level: 36% were coded as level 2 in ECE3-P; and 25% in ECE1-L. Evidence evaluation meeting each of the four criteria for evidence evaluation: a) identifying patterns in data; b) connecting data and claim through justification; c) establishing comparison with other data; and d) explicitly evaluating one or several alternative claims (see Table 4.5), were identified in children's talk in ECE3-P; whilst in ECE1-L children did not explicitly express patterns recognition (a), nor evaluated alternative claims (d). Justification was only found in two occasions in ECE1-L and in nine in ECE3-P. It is a low number of cases, but it should be noted that this is one of the most difficult aspects of the use of evidence for older students (e.g. Gotwals & Songer, 2013).

In order to answer their own questions, children carried out experiments, observations and looked for information. It should be noted that questions related to processes could be better answered through prolonged observation, whilst others could be answered through experimentation.

In ECE3-P, the teacher wrote down children's questions and set up a display on the wall with three columns "what do we know?", "what do we want to know?" and "what did we learn?" and she also wrote down children's initial hypothesis for every experiment. In ECE1-L there was not such a display, but the teacher kept notes of children's questions. Figure 4.3 shows a detail of the "what do we want to know? column of the display. The questions range from features of a snail's body to a snail's biology or wellbeing. Some questions seem grounded on previous knowledge, for instance the need for calcium.

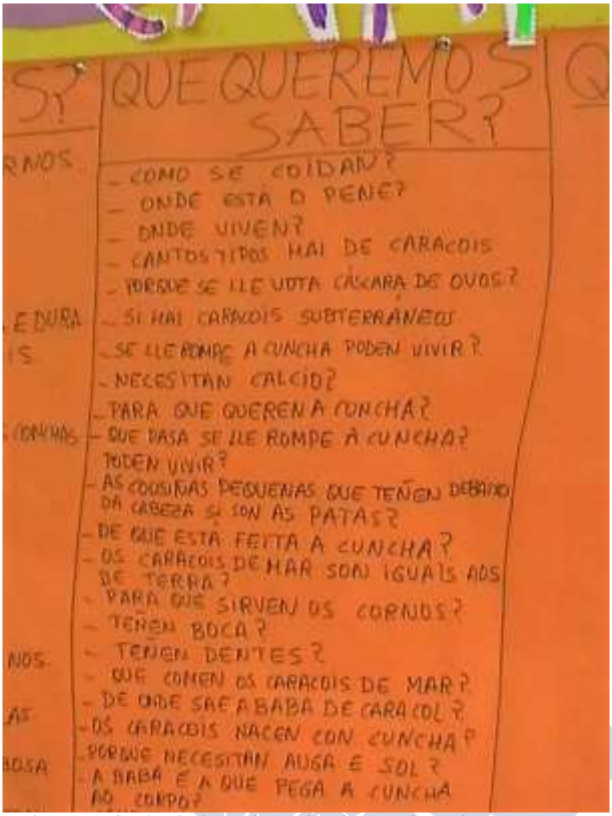


Figure 4.3. Detail of ECE3-P class display: What do we want to know?

Children's questions collected in the classroom display are translated in Table 4.8. The questions subsequently examined during the project are italicized. The questions are distributed in three types according to how they can be answered: by empirical first-hand data gathered either through purposeful observation or through experiments, or by seeking second-hand information (Monteira & Jiménez-Aleixandre, 2016).

All eight questions that can be answered by purposeful observation were addressed, although in many cases they were modified. From the four questions that can be answered by an investigation, there is one ("Can they live if the shell is broken?") that was not the object of an experiment, for breaking a shell on purpose was out of the question. Its examination through prolonged observation was made possible by an accident. “Can they hear?” was expanded into three more questions about the senses, explored through experiments ‘Smell’, ‘Taste’, and ‘Hearing’. Three more questions emerged about snails’ capacities that lead to carry out experiments about snails’ ability to walk over different surfaces and to balance on narrow wires or pieces of thread; and about snails’ strength. For each question in this category, children in both groups, ECE1-L and ECE3-P, were asked to suggest experiments that were planned with strong input from the teacher. Then they were asked to generate hypotheses contextualized in the experiment (but before carrying them out). Evidence in these classrooms was used to answer children’s questions and to test hypothesis when carrying out experiments. Selected examples from both groups are discussed below, in order to illustrate children’s interpretation of the results of experiments and how evidence was connected to conclusions through justifications.

Table 4.8. Types of initial questions: In italics, questions addressed in the project (*it could be answered by an experiment, but involving harm to snails) (Monteira & Jiménez-Aleixandre, 2016)

Type: can be answered by	Children's initial questions N=20
1. Empirical first-hand data gathered through purposeful observation: N=8	- *Do they have mouth?* - *Do they have teeth?* - *The little things under their head: are they legs?* - *What are the tentacles for?* - *Are snails born with shell?* - *What do they need the shell for?* - *Where does the snail slime come from?* - *Why are eggshells put there* [in the box]?
2. Empirical first-hand data gathered through an investigation or experiment: N=4	- *Can they hear?* [later expanded to: *Can they smell? Can they taste? Do they have touch?*] - What is the shell made of? - *Can they live if their shell is broken?** - *Is it slime what sticks the shell to the body?* [later modified as: *Which functions has slime?*]
3. Second-hand data, sought in the Internet, books or from family: N=8	- *How do we take care of them?* - Where do they live? - How many types are there of snails? - If there are underground snails - *Where is the penis?* - *Do they need calcium?* - *What do sea snails eat?* - Why do they need water and sunlight?

Regarding how children interpret the results of experiments: after a classroom discussion, they were asked to produce individual drawings for each experiment in a template with "conclusion" printed at the bottom. Children in ECE1-L were learning to write, and still found difficulties to write a complete word, so they were given word tags and, in large group, agreed in which order to paste them.

In ECE3-P children wrote the conclusion in their own words. The examination of drawings from ECE3-P focuses on the five experiments: 'Smell', 'Taste', 'Hearing', 'Surfaces' and 'Strength'. Children's writing skills were uneven, and the teacher's help was needed to interpret the texts. We examine the use of the lexical connector "because" (Ducrot, 1983) employed to connect evidence and conclusions. Some drawings were missing from the portfolios, either because children missed the session or because the drawings were not returned when they took the portfolios home to share them. Table 4.9 shows the frequencies of use in each experiment.

Table 4.9. Frequency of use of the connector "because" in the drawings of experiments in ECE3-P

Experiment	Smell	Taste	Hearing	Surfaces	Strength
No. because/ no. experiments	16/22	10/23	22/23	1/23	16/19

Although over half of the drawings (65/110; 59%) show the use of because to link claim and evidence, its use is uneven across experiments. The weakest results are found in experiment 'Surfaces' about the question, "Are snails able to walk over all surfaces?" We interpret this as a consequence of the different nature of data in the experiments. In this case most children provided a general claim "Snails are able to walk over all surfaces". Only one of them worded it in connection with data: "beqa[u]se they w[e]alk overrr all of them, eve[n] over the pins" (original language: "Os caracois son capazes de andar porr cuallier superficie porrce endaron porr todo ast por las chinchetas"). The use of because to connect data and claims is also found in the transcriptions of oral debates. This presence alone does not mean that children fully understand the role of evidence in supporting or falsifying claims; we consider it an indicator connected to others.

From the 16 children who handed in the five drawings, five used because in four cases, seven in three, two in two and two in one drawing. A similar trend appears in the cases of children handing in fewer drawings (see Table 4.10).

Table 4.10. Number of drawings of experiments handed by the students and use of connector "because"

No. drawings	No. students	Use of because	No. students
5	16	4	5
		3	7
		2	2
		1	2
4	6	3	3
		2	2
		1	1
3	1	3	1
2	1	1	1

Two examples of conclusions with a connector (children's spelling mirrored in translation): Carmen: "snails can smell because we put binegar [sic] and water ant they went to water" (original language: "Os caracoles ulen porque puxemos binagre e auga e foron para a auga") (experiment 'Smell'). Alberto: "s[n]ails donthear b[e]c[au]se we s[ho]uted andthey didnot [h]ide we play[ed]thetamb[our]ine and they didnot hi[d]e)" (original language: "os caraois nonoen pre l berranos y nonesodia -todaosopandie i nonse esonian") (see drawing of experiment 'Hearing' in Figure 4.4). One example of another drawing about the same experiment without a connector: Álvaro, "sna[ils] don['t] he[ar] s[ho]uted and din['t] hi[de] (original language: "carao no ollm bramo e no se esconian. Tamen tocamos os paus e o pandeiro").

Figure 4.4. Experiment 'Hearing'. Alberto, ECE3-P

Before carrying out the experiments, children shared their hypothesis. The term "hypothesis" was introduced by the teacher in ECE3-P, and appropriated by children. The following excerpt of conversation shows how children explain the meaning of this term, using for that the experiment 'Taste', in which they observed the behavior of snails in front of salt and flour:

> Teacher: What do we always do before carrying out an experiment?
> Several: Think!
> Several children: Hypothesis!
> Teacher: Let's see, what is a hypothesis?
> Ester: Each one says what she thinks is going to happen.
> Isabel: For instance, if they [*snails*] go to the salt, they die.
> Teacher: But… another children said no!
> Elena: But with the experiment of salt and flour every one said that they would go to the flour and not to the salt! Nobody said it was going to the salt.
> Roberto: Yes! We were right!

Carmen: Yes, in the salt and flour experiment everybody, everybody, everybody said they would go to the flour and nobody said they would go to the salt.

Isabel: Yes, yes… Because almost everyone said they would go to the flour, because they die.

Original language:

Mestra: Nós que facemos sempre antes de facer experimentos?

Varios: Pensar!

Varios: Hipótese!

Mestra: A ver, que é unha hipótese.

Ester: Cada uno dice lo que piensa que va a pasar.

Isabel: Por ejemplo, si van á sal morren.

Mestra: Pero outros decían que non!

Elena: Pero é que co experimento da sal e da fariña todos dixeron que iban ir á fariña e non a sal. Ningún dixo que ía ir a sal.

Roberto: Si!! Acertamos.

Carmen: Si, no experimento da sal e da fariña toditos, toditos, toditos dixeron que iba ir á fariña, ningún dixo que iba ir á sal.

Isabel: Si, si… Porque casi todos dixeron que van ir á fariña porque morren.

In this excerpt of conversation, children explain what is a hypothesis with an example from their experiences, making clear that they discriminate between what they thought before carrying out the experiment "Nobody said it was going to the salt"; and what happened "Yes! We were right!". Children know, because they have looked for information at home that salt is dangerous for snails, and that, in order to protect their vegetable gardens from snails, some people put salt around the plants, as stated by Isabel: "For instance, if they [*snails*] go to the salt, they die". In the following excerpt Carmen is reporting about an incident with one snail and the salt that took place while setting the experiment:

Carmen: [*we carried out*] an experiment with flour and salt. And we placed three snails in the middle [*amid flour and salt*] and they went towards the flour and then they ate it. But someone let a snail fall into the salt and we didn't know whether it was dead or not.

Researcher: And what happened?

Carmen: It was foaming! [...]

Elena: Silvia healed it. Silvia is a girl who poured a lot of water over it [...] First, she cleaned it very well and then we put it in a paper.

Carmen: Nooo! She took the snail like that and she cleaned it very well in her hand.

Roberto: Then she poured so much water that it stopped foaming.

Elena: And she cleaned all that slime […] and then we were worried about if it was dead or not. But Sol marked it with a red cross like in hospitals, and then next day we discovered that it was alive.

Researcher: How did you know that it was alive?

Elena: Because we saw it! [...] It was hidden in the shell.

Researcher: Yes? And did it come out of the shell?

Elena: Yeees!

Original language:

Carmen: Un experimento, con fariña e sal. Y pusimos tres caracoles en el medio i foron para a fariña e despois comérono. Pero alguén meteu a un caracol na sal e non sabíamos se estaba morto ou non.

Investigadora: E que pasou?

Carmen: Espumaba!!! […]

Elena: Silvia i curou o caracol. Silvia é unha chica que lle botou moita auga […] Que primeiro limpouno moi, moi ben e logo lle puxemos un papel.

Carmen: Nooon! Colleu así o caracol e limpouno moi ben na man.

Roberto: Despois botoulle tanta auga que deixou de espumar.

Elena: Y le limpiaba toda esa baba. […] E despois estabamos preocupados por se morrera ou se sobreviviera. Pero Sol logo púxolle unha cruz roja como nos hospitales e ao día seguinte descubrimos que estaba vivo.

Investigadora: E por que sabíades que estaba vivo?

Elena: Porque o vimos! […] Estaba escondido na cuncha.

Investigadora. Si? E saíu da cuncha?

Elena. Siii.

That unexpected event drove pupils to gather evidence through observation to test whether the snail would survive. As in the instance of the broken shell, discussed below, Carmen and Elena switched from considering just two different extreme states dead or alive, to take into account the process of healing.

In terms of the process of knowledge evaluation (argumentation), Elena supports her claim in the snail's behavior that allows them to know that it was alive, by implicit contrast with the previous day, when it was hiding, which made impossible to know if it was alive or dead. This argument has a metacognitive dimension as Elena is justifying how they knew that the snail was alive. Elena's argument is represented in Toulmin's format in Figure 4.5.

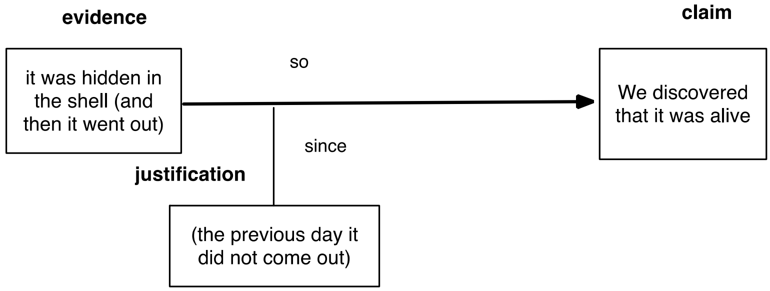


Figure 4.5. Elena's argument about the accident. Implicit knowledge between brackets.

Children experienced difficulties in producing appropriate hypotheses, they failed to distinguish expected data that could support or falsify them from claims, a difficulty reported in the literature (e.g., Jiménez-Aleixandre et al., 2000). Table 4.11 summarizes children's hypothesis for experiments 'Hearing' and 'Strength' in ECE3-P.

Table 4.11. Children's hypotheses for experiments hearing and strength in ECE3-P (*Italics*: falsifiable claims)

Experiment hearing: Can snails hear?	Experiment strength: Do snails have force enough to pull objects?
1. *Yes, they can hear because when we shout they will hide in the shell* 2. *Yes because when we shout they will escape* 3. No, because they are deaf 4. They cannot hear because they do not have ears 5. No, because they do not have eardrum	1. *It cannot pull the potato because its shell would break* 2. They have not much force because they walk slowly and they are small 3. No, because the potato is heavier and bigger [*than them*] 4. The shell is strong and can carry weight

Hypotheses 1 and 2 about experiment 'Hearing' focus on observable behavior and could be appropriate, while hypotheses 4 and

5 seem conclusions from previous observations or secondary information; 3 is not a hypothesis but a rewording of the claim. The teacher chose not to address these problems explicitly, but rather to focus on opposing claims, snails can or cannot hear, and on the predictions in hypotheses 1 and 2. Similar problems are found in the hypotheses about experiment ‘Strength’.Regarding experiment ‘Hearing’, the following excerpt corresponds to children reporting it during session 1, in ECE3-P:

> Marta: They don’t hear, because we shouted, and we banged sticks, but they didn’t hide [*in the shells*]. And if they hide it is because they hear, but they didn’t hide.
> Non-identified: No, because they lack hearing.
> Teacher: Lua, what did you do to see if they hide?
> Lua: I played the tambourine and they didn’t hide.
> Teacher: Playing the tambourine where?
> Lua: Close by.
> Teacher: Close to the snail.
> Several children: They are deaf!
>
> Original language:
> Marta: Non teñen ouvido, porque lles gritamos e lles tocamos os paus pero eles non se escondían. E se se esconden es que escuchan, pero no se escondieron.
> Neno: Non, porque non teñen oído.
> Mestra: Lúa e ti que fixestes para ver se escoitaban?
> Lúa: Toquei o pandeiro e non se escondían.
> Mestra: Pero tocar o pandeiro donde?
> Lúa: Cerca.
> Mestra: Cerquita do caracol.
> Varios: Están sordos!

Even though they experienced some difficulties in producing appropriate hypothesis, as discussed above, once they carried out the experiment, Marta uses appropriate evidence to support her claim (snails do not hear). She makes her argument stronger by appealing to a justification that connects evidence and claim ("if they hide it is because they hear, but they didn’t hide "). This justification is implicitly grounded in previous knowledge: firstly, that "snails are timid and withdraw into the shell", a statement from the "What do we know?" display hung in the classroom wall; secondly, that danger or threats cause snails to retreat into their shells. Marta's argument is represented in Toulmin's format in Figure 4.6.

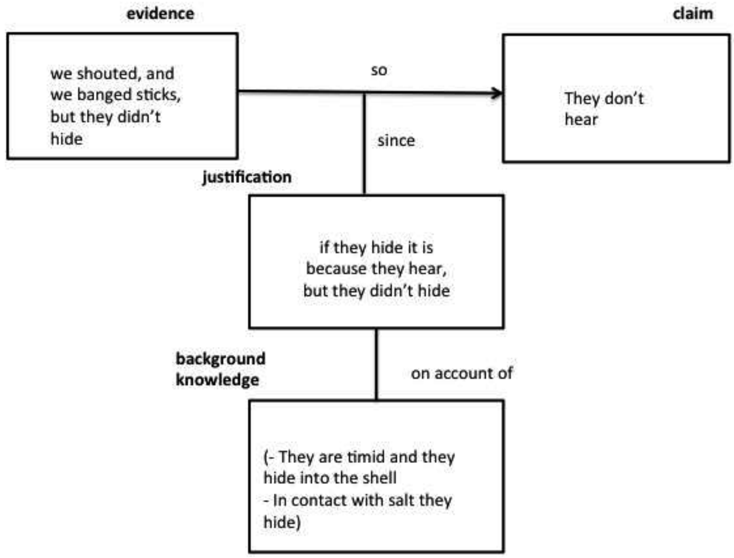


Figure 4.6. Marta's argument about hearing. Implicit knowledge between brackets.

In ECE1-L, children did not use the term hypothesis, as the teacher did not introduce it, although they did propose hypothesis before every experiment. The following excerpt of transcript corresponds to session 4, in ECE1-L. Children were repeating the experiment 'Balance', which consisted in placing the snails on three threads and checking whether they were able to stay on them. Three children were holding threads of three different materials: a cotton thread, a metal wire and nylon (original language below):

> Teacher: Pay attention! Is it going to stay on the thread?
> Several children: Yes.
> Teacher: Why? Who said it the other day, who? He said it very well. Why do we know that it is going to hang?
> Romeo: Because it has got slime.

Teacher: And what does slime do?
Not identified: It helps it!
Mario: It helps it to walk!
Teacher: It helps it to walk. It helps it to walk… where? Over any su...
David: Thing.
Gabriel: Surface!

Original language:
Mestra: Atentos, eh. Vai quedar colgado do sedal?
Varios: Si.
Mestra: Por que? Quen o dixera o outro día, que o dixera moi ben? Por que sabemos que se vai quedar colgado?
Romeo: Porque tiene baba.
Mestra: E a baba que fai?
Non identificada/o: Ayudarle.
Mario: Le ayuda a camiñar!
Mestra: Axúdalle a camiñar. Axudalle a camiñar por donde? Por calquera su...
David: Cosa.
Alejo: Sitio!
Mestra: Por calquera su…
Alejo: Sitio!
Gabriel: Superficie.

In this context, we consider that the children's claim or hypothesis is a prediction that the snails will be able to walk over a thread without falling. Romeo provides an explanation about why it would be so: "Because it has got slime". This is an explanation based on data obtained the first time they performed this experiment. Then Mario answers the teacher's question about slime's role: "It [*the slime*] helps it [*the snail*] to walk!" which is a justification connecting the prediction (snails will be able to walk) with the evidence from the first time they performed the experiment. This is one out of two justifications identified in ECE1-L. It could be considered as cooperation between Romeo, identifying the slime as the element that helps the snails to stay in place, and Mario, identifying the slime's role. The teacher strategy involves prompting children's to discuss observations, and focusing in observation and information search of slime functions was a common theme along several sessions. It can be noted that teacher's last intervention is made with the aim to make children produce another claim: an overall conclusion for the experiment. Although they carried out the experiment with three different materials (nylon, fabric and metal) there is not explicit reference in their talk to these data, so this last one is a claim (conclusion) lacking explicit evidence.

Figure 4.7. Experiment 'Balance'. Sebastian, ECE1-L

Figure 4.7 shows Sebastian's drawing of the experiment 'Balance'. Three snails hanging from wires are depicted. The names of the materials that make up each wire are written on the left hand side. Underneath the tag conclusion, it is writen: "*snils* [snails] are equilibrists" (original language: os *caacois* son equilibristas"). This sentence was decided by the teacher, who gave word tags (in capital letters) to the children to paste them in order. Only the word "*snails*" was written by children.

In these classrooms, teachers demand children to support their claims with evidence and to discuss how they have learnt something, for instance with an experiment, as illustrated below. In session1, ECE1-L, the teacher was pointing to a drawing of experiment 'Smell' hanging on the wall:

Teacher: Look here, what did we do? What did we discover?
Several: About smell!
Sebastian: That they have [*sense of*] smell.
Teacher: How do we know that snails have the sense of smell? Sebastian, talk towards her, so she can hear you.
Sebastian: Because they can smell.
Teacher: Yes, but how did we know that? What did we do?
Alejo: That they smell through their little tentacles.
Igor: On a scrap of paper we poured water and another of ... water.
Teacher: No, what did we pour in the other one?
Several: Water!
Teacher: No, what did we pour in the other paper...? That was smelly…
Sebastian: Vinegar!
Alejo: They do not like vinegar.
Teacher: And do you know what, Sabela?
Alejo: They do not like vinegar!
Teacher: They do not like vinegar.
Unidentified child: And besides they turned back [*from vinegar*].
Teacher: And then we found out that snails have smell where?
Several: In the little tentacles.

Original language:
Mestra: Que fixemos aquí? Que descubrimos?
Varios: O do olfato!
Sebastián. Que teñen olfato!
Mestra: Por que sabemos que teñen olfato os caracois? Sebastián, fala cara ela, se non, non te escoita.
Sebastián: Porque huelen.
Mestra: Xa, pero por que o soupemos? Que fixemos?
Alejo: Que huele por los cuernos pequeños!
Igor: En un trocito de papel el auga y otro de… y otro de… agua.
Mestra. Non, en un lle botamos auga e no outro lle botamos…
Varios: Auga!/Agua!
Mestra: Non, que botamos ao outro papel? Que cheiraba moito...
Sebastián: Vinagre!
Mestra: E sabes que, Sabela?

Alejo: O vinagre non lles gusta!
Mestra: O vinagre non lles gusta.
Nena non identificada: E ademais daban a volta!
Mestra. E despois descubrimos que tiñen o olfato donde?
Varios. Nos cornos pequenos!

Sebastian's difficulties in distinguishing claim and evidence can be noted in this excerpt. When asked how they found out that snails do not have the sense of smell he answers with the conclusion of the experiment "because they can smell", although another child offers a piece of evidence in snails' behavior: "they turned back".

In these classrooms' culture, claims are not accepted unless there is evidence to support them, as illustrated by this discussion about young snails and adults in session 2, ECE3-P:

Carmen: That some [*snails*] go faster than others.
Teacher: Which ones?
Carmen: The little ones.
Unidentified child: Smaller ones go faster because they weigh less.
Teacher: But we don't know whether this is true or not, we would need an experiment.

Original language:
Carmen: Que uns iban máis rápido que outros.
Mestra: E cales iban máis rápido?
Carmen: Os pequenos.
Non indentificado: Que os pequenos iban máis rápido porque pesan menos.
Mestra: Pero iso non sabemos si é certo ou non, temos que facer un experimento.

Results indicate that children in ECE are able to pursue answers to their questions given appropriate learning environments. By doing so, they support their claims with evidence. In order to pursue answers to their questions, they carry out observations, information search and they are able to plan experiments with strong input from their teachers. They understand that results from the experiments can be used to test their hypothesis. Even though, sometimes they find difficulties in producing hypothesis that can be tested through experimentation.

The main differences between ages and educational levels are that older students (ECE3-P) support their claims with evidence more often and also there is a greater number of evidence statements in the highest level of complexity. This finding can be related to the age of the pupils, but also to the fact that the older children in the study have been engaging in long term science projects with the same teacher for three years, along which they devoted great part of the time to engage in discussion about what and how they know what they know; whilst younger children (ECE1-L) are in their first school year.

4.5 RESULTS: WAYS OF GATHERING EVIDENCE AND THE ROLE OF PURPOSEFUL OBSERVATION

This section addresses research question 2, *Which ways of gathering empirical evidence are jointly constructed by children and their teachers during the project? Which is the role of observation in this context and which are its features? What are the differences in gathering evidence between first and third year of ECE?*

Evidence in these classrooms comes from three sources: a) it is generated in the course of experiments; b) it is gathered through purposeful observation, and c) it is gathered through information search. It should be noted that both experiments and purposeful observation generate empirical first-hand data, in contrast to second-hand data acquired from other sources. In ECE3-P, pupils and teacher referred to these two ways of generating evidence by different names: "to investigate", for short-term planned experiments, and "to discover", for purposeful observation (although it does not mean that observations were non-planned). This is a distinction introduced by the teacher.

We call purposeful observation that which takes place in these classrooms. We use it to refer to prolonged observation that had a particular focus, was guided by the teacher, discussed and used to test claims and to compare initial models with later ones. The notion of active purposeful observation draws from dialogic teaching (Alexander, 2008), medical training (Morris, 2007), and educational research (Merriam, 2009). Our suggestion is that it can be extended to children's observation of beings or phenomena. Purposeful observation was found to be an useful tool for learning in two contexts:

- First, to follow processes that occur along a prolonged time, such as the healing of a broken shell and the healing of a snail in ECE3-P; and the reproduction of snails in ECE1-L and ECE3-P.

- Second, to answer questions such as “how are snail’s mouthparts” in both classrooms. This last one is discussed in depth in order to answer the third research question.

According to its source, there is a majority of evidence that comes from first-hand data, gathered by children either through purposeful observation or through engagement in experimentation. As shown by Figures 4.8 and 4.9, summarizing sources of evidence in ECE1-L and in ECE3-P, most data that evolved into evidence were gathered through purposeful observation (left column in the Figures 4.8 and 4.9, labelled “observation”), which supports the importance of promoting this practice in early years’ science.

Regarding differences between years, results show that, in proportion purposeful observation takes more room in the generation of evidence in ECE1-L (32 out of 44 of evidence statements; 72.73%) than in ECE3-P (30 out of 57; 52.63%). Most evidence statements codified as level 2 were obtained through purposeful observation in ECE1-L, whilst in ECE3-P they are distributed among the three sources: purposeful observation (7), experimentation (6) and secondary sources (8).

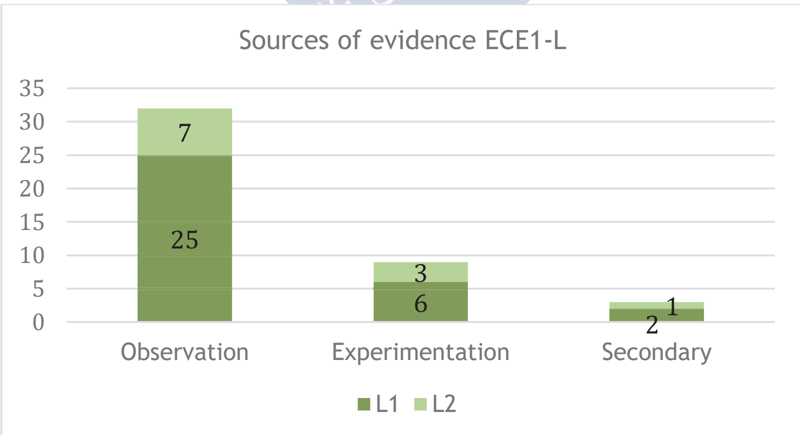


Figure 4.8. Evolution of data into evidence in ECE1-L, according to its source

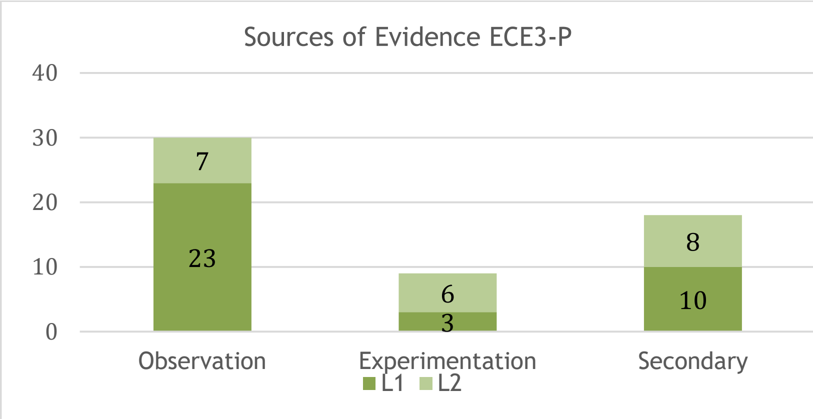


Figure 4.9. Evolution of data into evidence in ECE3-P, according to its source.

Regarding the healing of the broken shell in ECE3-P, the opportunity to observe this process emerged from an unexpected incident:

Teacher: What else did we discover? What happened that day that a boy grabbed a snail and what happened? And then you were sad?
Pupils (several): That the shell broke.
Teacher: And what did we think?
Pupils: That it would die.
Teacher: And what did we discover?
Pupils: That the shell grew again!
Ester: That with the eggshell the calcium is put in the shell. Because it has the calcium.
Hector: Because they eat it [*the eggshell*].
Marta: Yes, and then it is not smashed because it is tougher.

Original language:
Mestra: Que máis cousas descubrimos? Que pasou un día que un neno colleu un caracol e que pasou? Que despois estabades tristes?
Varios: Que se lle rompeu a cuncha.
Mestra: E que pensamos?
Varios: Que morría.
Mestra: E que descubrimos?
Varios: Que lle nace outra vez a cuncha!

Ester: Que con la cáscara de ovo se le pone en la cuncha el calcio. Porque tiene el calcio.

Héctor: Porque la comen.

Marta: Si, e despois non se destroza, porque é máis resistente.

This is an example of an intertwining of several scientific practices, as well as of cross-cutting concepts and core ideas. Evidence is gathered in order to answer the question, through a collaborative effort of the learning community involving analyzing and interpreting data, resulting in the claim that the shell grew. The initial question, framed in an opposition between being alive or dead and worded as a yes/no issue, is transformed into the examination of the process of shell regeneration. Ester adds a justification about the role of calcium in this process, and Marta complements it with a statement about the effect of calcium in shell's toughness, grounded in scientific knowledge; this connects the process to two other initial questions about calcium and eggshells (Figure 4.3, display with initial questions, reproduced in Table 4.8). As this example illustrates, data come from different sources. The word *calcium* was introduced by one of the children who brought it from home, after a web search at the beginning of the project and which was already familiar to the children because it is commonly heard in dairies commercials. This word was given a meaning through its function: calcium is a component of structures such as eggshells and it makes snails' shells tougher. The prolonged observation of this recovery provides opportunities for an initial contact with the crosscutting concept of stability and change. Larger time scales are needed in order to observe changes, as acknowledged, for instance, in the NRC framework (2012).

In both classrooms, the snails in the box were carefully observed and discussed every day. Children had the opportunity to observe snails' eggs and new-born baby snails. Some of 3-4 year-olds experienced problems in accepting the change from egg to baby-snail, which took place during school Spring break. The teacher provided them with opportunities to observe the baby snails with instruments such as amplifying lens and stereomicroscope. Even though part of the children engaged in discussions about the observed parts of the baby snails, such as the shell, and compared its features with those of the older snails, some of their peers were reticent to accept the change during the first days. In the ECE3-P class, children discovered the little snails, but the teacher (who had not very good sight) told them they were excrements. Children supported their claim with evidence: "No, *[they are snails, not excrements*], they have little horns".

Purposeful Observation lead to experiments, too. When cleaning the snails' box, children observed changes in the color of the excrements. Children observed that the color of excrements was related to the color of food. Then they experimented giving to the snails food of a single color, recorded the outcomes, described as "we investigated it", and identified a pattern, as shown in Ester's (ECE3-P) generalization "poo of the color of what they eat":

> Ester: With [*eating*] carrot they poo orange, because carrots are orange...
> Researcher: And if they eat lettuce?
> Several children: Green!
> Ester: Poo of the color of what they eat.
> Researcher: And what did you do to know that?
> Several children: We investigated.
> Ester: [*We saw*] Poo of different colors and then we investigated it.
> Carmen: Look, we have everything it liked there [*classroom display*]. It liked almost everything, but the broccoli it did not like it.
> Non-identified: Nor the nuts.
> Alberto: But they do eat soil… if they eat soil they made black poo.
> Teacher: Why do you say they eat soil?
> Álvaro: Because one day we did not bring them food and they ate soil.
>
> Original language:
> Ester: Con zanahoria hacen caca de color naranja, porque la zanahoria es naranja…
> Investigadora: E se comen leituga?
> Varios: Verde.
> Ester: Caca del color de lo que comieron.
> Investigadora: E como fixestes para saber iso?
> Varios: Investigamos.
> Elena: Cacas de varios colores y luego lo investigamos.

> Carmen: Mira, temos aí todo o que lle gustou, gústalle casi todo, pero o brécol non lle gustou.
> Non identificado: Nen as noces.
> Alberto: Pues que si comen tierra… si comen tierra echan caca negra.
> Mestra: Porque dicides que comen terra?
> Álvaro: Porque un día no les traímos comida y comieron terra.

It should be noted that generalizing requires children to be able to recognize patterns, which is a demanding operation. Identifying patterns is essential for building scientific knowledge, as patterns of forms and events are a guide for organizing and classifying. Patterns can also originate questions about relationships between elements and the factors that influence them, such as the relationship expressed by Ester.

In ECE1-L, children were prompted by the teacher to discuss their observations about the excrements' color and to register data about food they gathered through engagement in purposeful observation. They represented them in a display that was hung on the wall: it consisted on two columns; one in which children placed pictures of the food eaten by snails, and another one for the food they did not eat. Children expressed the relation as follows:

> Romeo: When they eat tomato, the poo comes out red, when they eat lettuce, the poo comes out green and when they eat fish and flour, white poo.
>
> Original language:
> Romeo: Cuando comen tomate les sale la caca roja, cuando comen lechuga les sale la caca verde, cuando comen pescado e harina, la caca blanca.

It can be noted that they did not produce a general claim, like the generalization and pattern identification expressed by Ester, instead they referred to individual claims and pieces of evidence. We suggest that this might be due to the fact that identifying a pattern is more demanding than coordinating a single piece of evidence with a claim, and it might be more difficult for younger children.

Results indicate that purposeful observation is the main source of evidence in both ECE classrooms. Among its affordances, prolonged observation allows following processes, essential in life sciences, and that it might be easier for younger students than other practices such as planning experiments.

Observed differences between ages and educational levels seem to support the greater easiness of younger student to engage in PO compared to other practices: in ECE1-L the predominance of PO as the main source of evidence is higher than in ECE3-P. In ECE3-P it is the main source for evidence, although for the higher sophistication level it is balanced with the other two sources: experimentation and second hand data. A second finding is that younger children were not able to produce any pattern claim, whereas older children derived it from PO. Also, children in ECE3-P explicitly discriminate in their talk between the two ways of gathering first-hand evidence: to "investigate" for experimentation; and to "discover" for PO.

4.6 RESULTS: USING EVIDENCE FROM PURPOSEFUL OBSERVATION TO REVISE IDEAS

This section answers research question 3, *How do children use evidence to revise their understandings? What are the differences between first and third year of ECE in the revision of understandings under the light of new evidence?*

The examination of how children used data from purposeful observation to evaluate or revise their emerging models about snails is framed in an approach that considers the articulation of practices with core ideas. Because of the teachers' focus on continuity, conceptual topics, such as, for instance, functions of slime or parts and features of a snail's body, were recurrent along the sessions. These recurring topics were explored through a combination of purposeful observation, experiments and second-hand information. Purposeful observation was a driving force in the revision of ideas. Certainly, mere observation does not produce conceptual change.

The way the teachers scaffold purposeful observation is illustrated with the process of how children revise their ideas about snails "teeth" and "tongue", which recurred through four (in ECE1-L) and five (in

ECE3-P) videotaped sessions. Changes in children's mental models are reflected by changes in children's explanations and by changes in their drawings (expressed models), which are discussed.

By the last week of January, children in ECE3-P had observed the snails for two weeks, but they had not gathered data or information about their organs. The teacher asked them to draw "what they thought was inside the snail's mouths". Twenty drawings were returned, all of them representing the mouth as a semi-elliptical shape, like a human tongue, and 10 of them with teeth around it or at the end. Eighteen labeled it "tongue", a term used to refer to mouthparts that can be projected outside. As Inagaki and Hatano (2006) acknowledge, human-based inferences or person analogies are useful for biological understanding, and should be viewed positively, as reflecting a child's adaptive mind. Figure 4.10 reproduces a representative drawing.

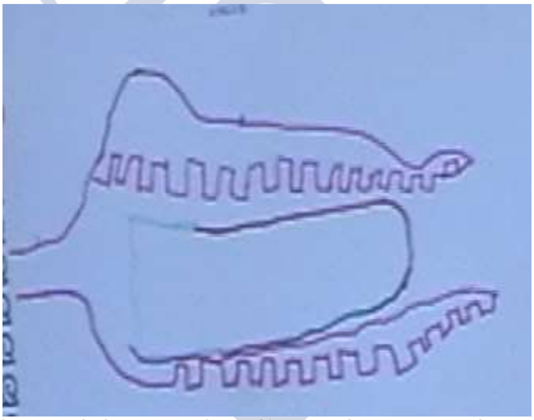


Figure 4.10. Initial drawing of snail's mouthparts. Danilo, ECE3-P

Children performed observations during the course of experiments: while conducting experiment 'Taste', the teacher prompted the children to observe the snails feeding on flour. Daily observation also generated a discussion on session 1, ECE3-P, about the deep holes ("tunnels") in food.

Ester: They don't eat carrots like we do.

Pupils (*several, talking at the same time*): They make little holes! / Yes, they do.

Teacher: Why do they make holes?

Several: Because they have teeth.

Children discuss about the mouthparts. Noise. The teacher intervenes to end the debate, telling that they need to study how teeth are.

Teacher: Because they are not like ours: Are they?

Elena: Oh my, if they have them, we don't know that yet.

Teacher: True, we don't know that yet.

Alberto: They are smaller.

Teacher: That is what Alberto imagines. We will need to test it.

Marta: I think they do have teeth, because otherwise they could not make these tunnels.

Álvaro: If they did not have teeth like those, like ours, they would not eat this way.

Ester: Maybe they have another shape, or another color.

Original language:

Ester: La zanahoria no la come como nosotros…

Varios: Hacen buratiños / Si, hacen buratiños!

Mestra: Por que fan buratiños?

Varios: Porque teñen dentes.

Entran nun debate sobre as partes da boca. Ruído. A mestra intervén para rematar o debate, dicíndolles que teñen que estudar como son.

Mestra: Por que non son como os nosos, verdade?

Elena: Ai, si os teñen, aínda non o sabemos.

Mestra: Claro, aínda non o sabemos.

Alberto: Son máis pequenos!

Mestra: Eso é o que imaxina Alberto, teremos que comprobalo.

Marta: Eu creo que si que os teñen, porque, si non, non poderían facer estos túneles!

Álvaro: Si no *tenieran* dientes así, como los tenemos nosotros no comerían así.

Marta: Pero ao mellor os teñen doutra cor ou doutra forma.

Several scientific practices are enacted in combination in this excerpt. Children interpret data, holes in food and glimpses of mouthparts, to construct their explanations, communicated through class talk: snails have teeth, but they are not like ours, they are smaller because they make little holes. Data are based on observation, in particular indirect data, through the tooth marks, used as evidence of the existence of teeth, in a way similar to their use by biologists to identify animals. It can be seen how Marta proposes an alternative, according to the characterization tool she has built: identifying *shape* and *color*. It should be noted that at this age, children easily recognize these two features. Building knowledge from children's ways to perceive and make sense of their surroundings is a relevant feature of these teachers' approach.

In the second week of March, in ECE3-P, the teacher asked children to collect information about snails' mouths at home. In session 2 the children shared this second-hand information from web searches, such as the term radula, its ribbon shape and the little spikes on it:

Teacher: Let's see, Luis.
Luis: It is shaped like a ribbon.
Teacher: It is shaped like a ribbon, and: What are the little spikes for?
Luis: To scrap off food.
Teacher: To scrap off food. Then: Does it have teeth?
Luis: No, it has little spikes.
Teacher: […] And what did we say? What does it looks like?
Isabel: Teeth
Teacher: No.
Alicia: Fangs.
Teacher: No. Let's see, what did we say, it has got a lot of spikes, it is similar to…
Several: A saw!

Original language:
Mestra: A ver, Luis.
Luis: Ten forma de cinta.
Mestra: Ten forma de cinta, e para que ten esos piquitos?
Luis: Para raspar a comida.
Mestra: Para raspar a comida. Entón ten dentes?
Luis: Non, ten piquitos.
Mestra: […] E que dixemos? A que se parecía?
Isabel: A dentes.
Mestra: Non.
Auria: A colmillos.
Mestra: Non. A ver, que dixemos, ten monton de piquitos é parecido a..

Varios: Unha serra!

Children revise their ideas, discarding anthropomorphic names: the chitinous spikes are no longer “teeth”, radula is the name of the “tongue” (although this term continues to be used) and snails do not chew, but rather scrape off food. Differentiation among similar structures is a step in the construction of science concepts. They use analogies, like ribbon, to share information. First-hand data are combined with second-hand data, as on the third week of March, when they watch a YouTube video of a snail feeding, in which, due to magnifying and good lighting, the radula can be clearly observed.

A critical revision of their previous models occurred, for ECE3-P, in session 3. The teacher asked each child to discuss her or his drawing, and to explain why it was drawn like that. From the 20 children, 14 justified their initial drawings saying that they thought it was "like ours". These models were then compared with new data from observation and the video.

Marta: They [*the spikes*] had hooks [*shape*]

German: And they are grey, too.

Alberto: And also that it [*radula*] helps it [*snail*] to take food to the intestine.

Researcher: But, did you see that?

Alberto: No.

The teacher shows the drawing that German brought from home, in which snails’ organs can be seen and also how the radula gets to the intestine. The teacher asks for more interpretations about the radula.

Roberto: We were impressed [*by the video*]!

Teacher: How did it work?

Children mimic radula’s movements sticking their tongues in and out. The teacher

Teacher: Were any of us right when we imagined what the radula was like?

Children: Nooo!

Teacher: And now: How would you draw it?

Children (several): Shaped like a ribbon.

Teacher: Does it have anything around it?

Children: No.

Original language:
Marta: Tiñan [*forma*] de gancho.
Germán: Ademais son grises.
Alberto: Y también que le ayuda a llevar la comida al intestino.
Investigadora: Pero iso vístelo?
Alberto: Non.
A mestra ensina o debuxo que trouxo Germán da casa, no que se ven os órganos do caracol e como a rádula chega ao intestino. Pide máis interpretacións da rádula.
Rodrigo: Quedamos impresionados.
Mestra: E como facía?
Comezan a sacar e meter a lingua, imitando os movementos da rádula.
Mestra: E alguén acertou cando imaxinabades como era a rádula?
Varios: Noooon!
Mestra: E agora, como a debuxaríades?
Varios: En forma de cinta!
Mestra: Vimos que ten o redor algo?
Varios: Non

The teacher prompted an explicit comparison of observations with their previous ideas, both in general terms, and in specific issues, such as where the spikes are placed (not around it). Children communicate new knowledge through multimodal discourse, for instance mimicking the movement of a radula with their tongues several times during this session.

In session 5, in ECE3-P, the researcher brought in the radula of a limpet, and they had the opportunity of directly observing it with the digital stereomicroscope. A new revision of their ideas took place, focusing on the new notions and their connection with evidence:

Teacher: What did snails do to food?
Children (several): Little holes
Teacher: Little holes. So we said that the "tongue" would need to have...
Children (several): Spikes.
[...]
Teacher: And: How would it work in order to make holes?

[...]

Ester: They would stretch it, pick up food, and withdraw it into the mouth.

Marta: True, like butterflies.

[...]

Alberto: Sol, it need to be rough so that they can scrap food off [*now, talking to another child*] because, if it is not rough it does not, not, not… it does not scrape off [...]. Certainly while the radula is spinning it is digging because it makes deep holes.

Original language:

Mestra: Que facían coa comida os caracois?

Varios: Buratiños!

Mestra. Buratiños. Entón como dixemos que tiña que ter a lingua?

Varios. Con piquitos.

[...]

Mestra. E como funcionarán para que faga os buratos?

[...]

Elena. A estirarán, pillarán a comida e a volverán a meter na boca.

Marta. É verdad, como as mariposas.

[...]

Alberto. Sol, tiene que ser rugoso para que a raspen, [*agora diríxese a outro compañeiro*] porque si no es rugoso no, no, no... no raspa..[...]. Seguro que mientras está girando la rádula se va metiendo porque hace buratos grandes.

The revision of ideas in this session included the shape of the radula and spikes, revised with data from direct observation that are compared to second-hand data, and its movements, evidenced by the deep holes they have been observing throughout the project. The teacher prompted them to propose explanations, in other words answers to "how" questions, about how this mouthpart with its tiny spikes would be able to make holes. Several children made proposals or analogies like Marta who compared Ester's explanation to butterflies, or a zip fastener. It is noteworthy that Alberto proposes a mechanism, spinning and digging, which accounts for the deep holes or "tunnels," observed in food. Explanations that include mechanisms are more challenging for students to construct. This lesson was one of the only times during the snails project in which pupils produced mechanistic explanations.

Figure 4.11 (from Monteira & Jiménez-Aleixandre, 2016) summarizes the revision of their models about mouthparts: "O" stands for evidence gathered through PO; and "S" for evidence from secondary data.

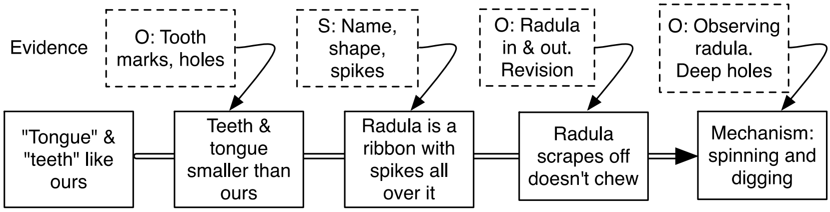


Figure 4.11. Evolution of children's ideas about snail's mouthparts in ECE3-P (Monteira & Jiménez-Aleixandre, 2016)

For ECE1-L, the revision of ideas about mouthparts took place in a similar way. After observing the snails for two weeks and before looking for any information about snail mouthparts, children were asked to produce a drawing of the animal.

Figure 4.12. First snail. Ariadna, ECE1-L

Figure 4.13. First snail. Aitor, ECE1-L

This series of first drawings of the snail represents children's initial ideas about the topic: in 12 out of 22 drawings examined, an anthropomorphic mouth was represented, in 7 of them with teeth, as shown in Figures 4.12 and 4.13, from Ariadna and Aitor, respectively.

The following weeks, children looked for information about this body part and observed the snail while eating. In session 1, children reported their findings and their ideas about "teeth":

> Teacher: Tell Sabela what we gave them [*snails*] for eating the last day?
>
> Amaro: Flour!
>
> Teacher: And how did they eat the flour?
>
> Sebastian: With the tongue.
>
> Teacher: What have we seen?
>
> Several: The tongue!
>
> Teacher: Tell Sabela what does the snail have in its tongue.
>
> Several: Teeth
>
> Teacher: Teeth, it has got teeth, Sabela. What was the name of the snail's tongue?

Romeo: Radula!
Teacher: Very well, very well, it is called radula.

Original language:
Mestra: Contádelle a Sabela que lles dimos de comer o último día?
Amaro: Fariña!
Mestra: E como comían a fariña?
Sebastian: Con la lengua.
Mestra: Que lle vimos?
Varios: A lingua!
Mestra: Contádelle a Sabela que ten na lingua o caracol.
Varios: Dentes.
Mestra: Dentes, ten dentes, Sabela. Como se chamaba a lingua do caracol?
Romeo: Rádula!
Mestra: Moi ben, moi ben, chamábase rádula.

Children in this class considered that snails had teeth, as they were necessary to account for the marks in the food, as explained by Sebastian, later in session 1:

> Teacher: How did they [*snails*] eat the tomato? And what did they make in the tomato?
> Several: Holes!
> Teacher: Holes, right? They made holes.
> Sebastian: With their teeth!
>
> Original language:
> Mestra: Como comeron o tomate? E que fixeron no tomate?
> Varios: Buratos!
> Mestra: Buratos, verdad? Fixéronlle uns buratos.
> Sebastián: Con los dientes!

By the end of session 1, children produced a second series of drawings of snails. From the eighteen drawings collected, only one human-like mouth, although without anthropomorphic teeth was represented. It should be noted that, although they kept on using the word “teeth”, their representations do not reflect any longer a human-like model of teeth. In three cases, children represented a thin line with spikes in it, accounting for the representations of radula they had seen in their web search.

In session 2, children observed the snails with an amplifying lens and a stereomicroscope, discussing its parts. Then, the teacher proposed a representation task, involving relating four of the parts of snails to its position in the animal's body. She handed each child four photographs of: snail's foot, mouth, tentacles and shell; and asked them to paste the pictures in the appropriate place in a sheet of paper that contained arrows that pointed to a central picture of a snail.

By the end of the month, through which they kept on looking for information, children produced a drawing of a snail's radula (N=18). All but one represented an organ with "teeth". These were represented either by lines or circles. Twelve children drew the radula like a circle and six did it like a line. Representative examples of both choices are shown in Figures 4.14 (circle, Ali's drawing) and 4.15 (line, Ariadna's). An oval shape covers children's names to protect their identity. Apart from children's name, there is another tag in both drawings: the word *radula*.

Figure 4.14. Snail's radula. Ali, ECE1-L

Figure 4.15. Snail's radula. Ariadna, ECE1-L

In session 5, the researcher brought the limpet's radula, which was observed through the stereomicroscope, like in ECE3-P. Children discussed its parts, identifying the "teeth" (sic) and discussing its color, shape and functions. They expressed surprise about the length of the organ, and proposed that snails had the radula inside the body and took it outside while eating. Children used mimics to explain this mechanism, recalling their observation of the snail eating the flour with that mouth piece. It should be noted that the mechanism proposed in ECE1-L is simpler than the one proposed in ECE3-P.

By session 6, children reviewed the pictures of the radula taken during previous session and produced drawings of it (N=22). In all of these drawings, the limpet's radula is represented as a thin line with "spikes", and none of them is closed in a circle, which conveys the main meaning they built for this organ. Differences between children's drawings of limpet's radula come in: a) the way to represent "teeth", either circular or elliptical shape (see for instance circles in Figure 4.16), dots or lines; b) the thickness of the organ; and c) its shape, given by how it is bent, as they were able to observe that the actual radula was bent several times to place it under the light of the stereomicroscope. Figure 4.16 shows a representative drawing of a limpet's radula.

Figure 4.16. Limpet's radula. Marilena, ECE1-L

These findings about changes in children's models in the light of new evidence support the role of purposeful observation in the evaluation of their own ideas.

4.7 DISCUSSION

This study seeks to shed light on the use of evidence in early childhood in the context of a project about snails spanning five months. Since this is a case study, there are limitations: for instance, we are unable to generalize our findings; however, a number of important issues do emerge from this work.

As a summary, it can be said that children in early childhood are able to use evidence to support their claims and answer questions, with increasing sophistication with age and educational level: there are a smaller number of claims supported with evidence in ECE1-L than in ECE3-P; and, by the third year, children's discourse includes more evidence statements involving epistemic judgment.

In the project, this first-hand evidence, from experiments or observation, is combined with second-hand evidence from web searches or family knowledge. Drawing from Alexander's (2008) notion of purpose in dialogic teaching, and from Morris (2007) and Merriam (2009), we define purposeful observation as prolonged systematic observation that has a clear focus, is guided by the teacher, recorded, explicitly discussed, and used to test claims and revise initial models. It must be noted that most of the evidence collected in both groups is empirical first-hand data, which according to previous studies (Delen & Krajcik, 2015; Hug & McNeill, 2008) evokes in pupils a higher sense of ownership.

An indication of the significance of purposeful observation in these ECE classrooms is that most of the evidence statements, 30 out of 57 in ECE3-P and 32 out of 45 in ECE1-L, correspond to the context of purposeful observation. A second claim derived from these results would be that the younger the children, this practice takes more space in comparison with others. Because this is the first study focusing on it, it is difficult to ascertain whether this frequency is related to students' age and developmental reasons or to the particular context of this project and the teachers' approach. We suggest that these findings point to the interest of paying attention to promoting systematic, prolonged observation as a context for constructing empirical evidence in early ages.

With regard to how these young children use evidence, one relevant finding is the role of evidence from purposeful observation in the evaluation and revision of their ideas about snails. Being able to review one's own ideas is essential for autonomous learning. An instance of how initial models are contrasted with evidence is the evolution of children's ideas about snails' mouths. As Gelman and Brenneman (2012) point out, through systematic observation children come to think differently about what they are observing. Thus, children were able not only to revise their ideas about the form and other external features of the radula, but also to propose a mechanism. In ECE3-P, the mechanism emerged as an explanation to account for the tooth marks observed in food. In ECE1-L, observation of the length of the limpet's radula, lead children to propose that snails would take it in and out for eating. This was reflected by the changes in their drawings of a radula: although the first ones were done after looking for information about the organ, only 6 of them are elongated, whilst in the second drawings all of them are. Differences between ages and educational levels come out in the complexity of the mechanism expressed by children, which is higher in ECE3-P. It should be noted that both mechanisms emerged from children's own observations and questions. This finding is aligned with

Siry and Max's (2013) who reported that a science curriculum including investigations mediated by kindergarteners' interests, supported children in developing and refining explanations.

We believe that the notion of purposeful observation and its role in the revision of ideas, are new and they are an original contribution of our study. It is known that long-term projects provide opportunities to build understandings (Gelman & Brenneman, 2012), and that epistemic and social elements are most effectively incorporated as part of extended sequences of instruction (Duschl, 2008). What our study adds is a characterization of the features of observation brought by this extended time. Purposeful observation over an extended period enabled the study of processes: first, it enabled the children's exploration of biological processes, such as the development of newborn snails, healing from contact with salt or the regeneration of a broken shell. Second, it enabled the researchers' examination of learning processes, such as the evolution of ideas across several months, rather than only the difference between initial and final ideas (products). Our interest lies not only in what children can learn, but also how we can characterize learning environments and strategies that support learning.

In reference to the development of data into evidence, our findings point to the distinction between two levels or stages in the transformation of raw data into evidence (Aikenhead, 2005; Duschl, 2008). First, we suggest that studies about early childhood and primary schooling should identify descriptive statements or raw data, alongside argumentative components, such as evidence, in order to better document how the transition from data to evidence occurs. Second, the identification of these two levels may have potential interest for argumentation progressions, and in particular for entry points in early childhood. In their work about practice progressions for evidence-based explanations beginning in 4th grade, Gotwals et al. (2012) place in level 1 "student makes a claim", with two sub-levels, with and without scaffolding; and in level 2 "student makes a claim and backs it up with appropriate but insufficient (partial) evidence", also with two sub-levels. Gotwals and Songer (2013) identify levels 1 to 3 with scaffolded practices, beginning with a question provided to students. We suggest that, in kindergarten and early primary, two levels that would be previous to those from Gotwals and colleagues, or overlapping with them, could be: (1) selecting data appropriate for being transformed into evidence related to a claim; and (2) identifying potential (appropriate) evidence that could confirm or disconfirm a claim. Both processes would be scaffolded, as is the case in our study.

As noted above, in both classrooms most of evidence statements identified in the study are related to purposeful observation. In ECE1-L the majority of those in the higher evaluative level, L2, correspond to purposeful observation, whilst in ECE3-P there are distributed among the three sources of evidence identified in our coding scheme. We suggest that, in ECE1-L there is prevalence of purposeful observation as a source of evidence, independently of the sophistication of the evidence statement, as it might be an easier practice to engage in at these ages, than others, such as experimentation. Whilst, when children get older, such in ECE3-P, experiments provide a frame where the relations between claim and evidence are more explicit and clear-cut from the beginning. In the case of purposeful observation, the claim may be derived from evidence, emerge later in the process, and the relations may be more diffuse. If this is so, the implication is a need for framing purposeful observation in the process of constructing evidence-based explanations more explicitly. It should be noted that our suggestion is to combine experiments and purposeful observation, not to focus only on the second.

Teacher's strategies to scaffold pupils' performances are relevant to understand children's level of engagement in the scientific practices in both classrooms. These strategies are discussed in depth in chapter 7.

We suggest the importance of promoting purposeful observation as a source of evidence in early childhood and in the first years of elementary education, in particular in life sciences, because it supports students in collecting and interpreting data, in the transformation of data into evidence, and in using evidence in order to revise their understandings. Purposeful observation is complementary to investigations and experiments; it poses, perhaps, fewer difficulties for young children. As research shows, even adolescents have problems when planning investigations (Crujeiras & Jiménez-Aleixandre, 2017). What we are proposing is to use them in combination, not to focus only on purposeful observation; however, we suggest that in early ages purposeful observation should be given more emphasis.

We think that our results support Metz (2011) and Gotwals et al. (2014) regarding the relevance of instructional opportunities over developmental constraints. The context is crucial for children to be able to develop their competencies, especially in ECE. Prolonged time, attention to children's interests, promoting children's active role and starting from what is known to them are among of the features of the teachers' approach, parallel to those highlighted by Gelman and Brenneman (2012), that allowed children to engage in science in sophisticated ways. Their teaching approach allowed children to build scientific knowledge by engaging in the practices of science, becoming aware of how it is built. Children learned not just about the contents, but also appropriated part of the procedures and developed skills, as recommended by curricular documents, such as those developed by the OECD (2015) and the NRC (2012).

5 MODELS AND REPRESENTATIONS IN EARLY CHILDHOOD: EVOLUTION FROM ECE1-L TO ECE3-L

In this chapter the second research objective, *To explore what features has children's use and construction of models*, *what is the role of representations in this practice and how it evolves from ECE1-L to ECE3-L,* is addressed. The analyses presented here were partly carried out in collaboration with other researchers, during the course of two research visits. Isabel Martins (Monteira, Jiménez-Aleixandre & Martins, in review) collaborated in the social semiotic analysis, which was carried out in order to answer the first and second research questions. Regarding the third research question, the analysis was carried out in collaboration with Christina Siry (Monteira, Jiménez-Aleixandre & Siry, in review).

5.1 INTRODUCTION

The focus of this chapter is to examine changes in the ways the pupils from the longitudinal study group (ECE-L) engage in the scientific practice of using and constructing models and representations, along the three years of ECE, in the context of long-term school science projects.

Performances within the same group at different stages of ECE are compared. We begin by zooming in children's first year of schooling, ECE1-L, in order to examine two series of expressed models (drawings) devoted to represent the same science content, made within a month of difference. Changes in children's models and communicative resources appropriated by them in the context of the science classroom are identified. Then, we take a broader perspective and move on to explore what how children's engagement in modeling practices increases in complexity along the stage.

The objective was expanded into three research questions, the first and second addressing meanings communicated by children's expressed models in ECE1-L; the third addressing changes in their engagement in modeling from ECE1-L to ECE3-L:

1) Which science meanings about snails are constructed and communicated by ECE1-L children in their expressed models and how do they change during the year?

2) Which communicative and representation resources of the science classroom community are appropriated by ECE1-L children?

3) How do children's ways of engagement with scientific expressed models become increasingly more complex from ECE1-L to ECE3-L?

First, the participants and the context are introduced; second the data analyzed and the analysis tools developed are presented. Then, results are discussed.

5.2 PARTICIPANTS AND CONTEXT

The participants are the group of ECE-L and their teacher, who were accompanied along the three years of ECE. The number of students in the group varied along the three years: the first year (ECE1-L) there were 23 children in the class (10 girls and 13 boys); two boys arrived in the second year of the study (ECE2-L), and one boy and one girl left in the third one (ECE3-L). At the beginning of the study, children were 3 – 4 years old and when it finished they were 5 – 6.

Children in ECE1-L were engaged in the 'Snails project', discussed in depth in chapter 4. In ECE3-L, the group was involved in the 'Clouds project' for five months. They learnt about cloud formation and types of clouds, water state changes and the water cycle. The group went out to the school courtyard to perform observations of the clouds. Along the project, four experiments about water state changes, gas to liquid, under different conditions were carried out. Children enacted models of the three states of water and the water cycle with their bodies. They used other types of models, as well, such as an Earth globe and the 'Ecosystem', a little greenhouse with a pond in which they planted seeds. Children brought pieces of information about clouds from home to share with their classmates and searched the weather website and other sites with information about clouds. Table 5.1 summarizes the timeline of the 'Clouds project'.

Table 5.1. Timeline of the 'Clouds project' in ECE3-L

Session-Date	Contents and children's actions	Children's products
1 - 15/01	- Motivation session: there are pictures of clouds on the classroom walls - Clouds types, formation, water cycle - Observing clouds in school courtyard	
2 - 20/01	- New pictures of clouds - Clouds' color and position - Observing clouds in school courtyard	
3 - 22/01	- Weather, the teacher reads a book called 'Atmospheric Phenomena' - Information from home: types of clouds and formation, cooling and condensation - Observing and discussing clouds' pictures	- 19 Drawings of the sky
4 - 15/02	- The teacher introduces one instrument to use for observations, the 'Cloudscope', and the 'Clouds Observer Credential' - Matching the clouds' pictures in the 'Cloudscope' with the ones hanging on the wall	
5 - 17/02	- Observing clouds in school courtyard with 'Cloudscope' - Experiment 'Evaporation': pouring water in two airtight closed bags and in two open glasses and leaving them inside and outside the classroom. Predictions: a cloud is going to be formed	
6 - 19/02	- Information from home: cloud formation, evaporation of water - Experiment 'Evaporation': control of the bags - Experiment 'Boiling': observing water boiling and its condensing on the surface of a mirror - Applying knowledge generated by the experiment 'Boiling' to explain the experiment 'Evaporation'. Comparing bags and glasses - Frost	
7 - 23/02	- The teacher reads a tale about clouds - Observing clouds in school courtyard	

	- Making a "cloud" with breath in the 'Cloudscope' - Experiment 'Evaporation': control of the bags. New explanations	
8 - 25/02	- Repeating experiment 'Boiling' - 'Boiling game': modeling the experiment with their bodies	- 20 Drawings of experiment 'Boiling'
9 - 26/02	- Introducing the model 'Ecosystem', a little greenhouse with a pond and planting seeds in it	
10 - 29/02	- Snow	
11 - 3/03	- Weather and types of clouds - Observing that the plants of the model 'Ecosystem' have grown - Experiment 'Making a cloud': observing a swirl of water drops inside a jar, created by putting ice on the top and warm water on the bottom	
6/03 (not recorded)		- 21 Drawings of black and white cloud
12 - 7/03	- Experiment 'Making rain': observing condensation of water by putting ice in the model 'Ecosystem', in large (classroom) and small (3-4 children) groups - Rain formation	
13 - 10/03	- Repeating experiment 'Making a cloud' - The teacher pours perfume in the class. The children explain that the smell of perfume and smoke arrive through the air - Observation of the particles of dust in the air with the projector	
11/03 (not recorded)		- 20 Drawings of measures from experiment 'Evaporation'
14 - 16/03	- Meaning of signs in drawings of measures from experiment 'Evaporation' - Reviewing the experiment 'Making rain'; droplets in the air, the air is everywhere, like the dust	-18 Drawings of experiment 'Evaporation'
15 - 17/03	- Watching a video about the water cycle - States of water, clouds, rain, snow - Reviewing experiment 'Evaporation' - Repeating 'Boiling game' - 'Three states game' and 'Water cycle game': modeling these phenomena with their bodies	- 19 Drawings of the three states of water
16 - 5/04	- Watching a video about the three states of water	

	- Repeating 'Three states game'	
17 - 6/04	- Repeating experiment 'Making a cloud'	- 19 Drawings of experiment 'Making a cloud'
18 - 12/04	- Interpreting a poster of the water cycle - Planting seeds in the model 'Ecosystem'	
19 - 4/05	- Watching a video about the water cycle - Using an Earth globe to explain that water cycle does not stop at night - Watering plants in ecosystem - Reviewing experiment 'Making rain'	-21 Drawings of the water cycle
20 - 11/05	- Types of clouds - Observing clouds in the school courtyard with the 'Cloudscope': the teacher asks children to identify cumulus, stratus, and cirrus, according to the criteria: see a lot of/little sky - Looking for definitions of cumulus, stratus, cirrus in internet	
21 - 12/05	- Identifying types of clouds according to color, height and size; using similarities with the pictures on the class wall in order to make an identification key - Repetition of experiment 'Making rain'	
22 - 19/05	- Fog is big low clouds - Suggesting ways to represent the fog with a drawing - Watching the video "making fog", identifying it as the same experiment as 'Making a cloud'	- Drawings of fog (not collected)
23 - 25/05	- Interpreting information from an online weather forecast, 'Meteogalicia': meaning of the symbols - Using an Earth globe to point out south, north. The teacher explains why there are warmer and colder places - Reviewing the key for clouds' identification - Repeating experiment 'Making rain'	- 21 Drawings of experiment 'Making rain'
24 - 9/06		- Cotton clouds: cirrus, stratus and cumulus (pictures, production not recorded)
25 - 15/06	-Reviewing: formation and types of clouds; rain, experiment 'Making rain', precipitations, the three states of water, water cycle, underground water	

As discussed in previous chapters, the teacher in the study has a particular focus on her students engaging in the practices of science. From the teachers' focus on observation, there was a related interest on documenting observations. For instance, children documented the contents and experiences of the projects with drawings. Children's drawings could be about actions or processes enacted in the classroom, such as an experiment, or about information, such as the food that snails had eaten. These drawings could include features of narrative and descriptive representations, respectively (Kress & Van Leeuwen, 1996). At the beginning of each science project, the teacher asked children to represent the phenomena under study, so that she could explore their ideas and follow their changes. For instance, in the 'Snails project', they were asked to draw a snail; in the 'Clouds project', the sky.

The teacher, like early childhood teachers in most countries, is a generalist. Thus, she also needs to support children learning other skills and content, including, for example, how to cut, paste, and color drawings; which are relevant for the productions examined in this chapter. Further, she places value on the children's final products being aesthetically pleasing, especially given that these are often showcased for parents and other community members once completed. For instance, the children used pencils first if possible and then finalized their work with permanent pens or other drawing tools. While producing drawings, children were getting acquainted with class culture rules, such as: clarity of the presentation, occupying the whole sheet and labeling it with their names.

Children in ECE are learning to write. They began writing only capital letters and the first word they learnt in ECE1-L was their own name: first they learnt the vowels and then the consonants. They were asked to label all their productions with their name. By ECE3-L they began to write lowercase letters too.

Regarding the use of representations, children asked to engage with different types of them along the three years of ECE. The teacher scaffolded children's use of visual representations, prompting them to discuss its meaning, features and use, what was being represented and how it was.

In order to illustrate children's engagement with representations, the course of session 1 from the 'Snails project' is discussed here. Table 5.2 summarizes the contents and length of the episodes in which the session was divided. A timeline summarizing all the sessions from the 'Snails project' has been presented in chapter 4 (Table 4.1).

Table 5.2. Episodes in session 1, 'Snails project'

Episode/ Length	Topic or action	Contents
1/3'47''	Topic: Weekend	Children narrate what they did during the weekend, as all Mondays
2/1'42''	Topic: Colored "poo"	Children narrate that they found out that snails' "poo" is the same color than the food they eat. For it, they use a representation of this finding, made by themselves, hanged on the wall
3/1'00''	Topic: Radula	Children explain how they saw a snail's mouthpiece while eating and that they found out the name of this part (radula) and describe its shape
4/4'28''	Action: Checking which food snails ate	Children check which food snails have eaten. Children show to the researcher the display they made about which food snails like and do not like
5/4'25''	Topic: experiment 'Smell'	Children narrate the experiment 'Smell', made in order to found out if snails have smell sense. They point to a drawing representing the experiment made by them They describe the function of tentacles: smell and sight
6/11'46''	Topic: Heart	One of the children presents to the rest of them a drawing he brought from home, which shows snails' inner body plan. The teacher helps him to point the place of the heart in one of the snails they have in the class, recalling one of children's questions: *Do snails have a heart?*
7/10'02''	Action: Observing the snails	Children manipulate and observe the snails. They talk about: snail's position in the box; poo; slime; eyes; skin; foot; mouth
8/ 15'58''	Topic: Snail's body parts	Children talk about snail's body parts and name: shell, foot, mouth, radula and tentacles
9/ 6'52''	Action: Drawing a snail	Children produce a second drawing of a snail (the first one, a month before)

On the one hand, this session is representative and serves for the purpose of illustrating the ways in which children produced and used representations along the sessions devoted to science projects. On the other hand, in order to carry out a social semiotic analysis of drawings, it is necessary to have into account the specific context in which they were produced, for instance, the instructions given by the teacher. The second series of drawings of a snail, subjected to social semiotic analysis, was produced during this session. The first series was produced a month before, after children had interacted with the snails for two weeks. In this session, the teacher used the presence of the researcher as a stimulus to revisit previous learning. She asked the students to tell the researcher what they had learnt about snails and to explain some of the activities carried out. The teacher prompted children to make their explanations as clear and detailed as possible, often questioning them about concrete aspects, repeating what they were saying in order to clarify if it was what they meant. She prompted them to explain and use the different representations displayed in the classroom, and provided time to discuss these with their classmates. Examples of these representations are drawings of experiments, information boards, or a diagram of snail's inner organs brought by one of the children, Mario. In previous sessions, children discussed and looked for information about snails' feeding, and found out that snails have a digestive system, as humans do. Children expressed that they also wanted to know whether snails have a heart. In this session, Mario brought the diagram to prove they have. The teacher took a snail from the box and asked him to point out for his classmates where the heart was located in its body, and Mario answered "Inside". Mario was not able to point the heart out by himself employing the diagram, and so the teacher helped him to use the diagram by showing where the heart was inside the actual snail.

Throughout the session, children went over different themes, devoting great part of it to discuss parts of snails' body, and dedicated about ten minutes to observe and manipulate the snails, while commenting on what they were seeing.

At the end of the session, they dedicated about seven minutes to reexamine and name the parts of snails' body they had observed and whose name was learnt in previous sessions; and about ten minutes to produce the drawings. The teacher introduced the task as follows: "It has been a long time [*one month*] since we have not drawn a snail. Now, we know many things… We know they have…". Next, the children named these body parts: shell, foot, mouth and radula; one child (non-identified) said snails had two tentacles while another one, Mario, disagreed and said they had four. The teacher then asked them about the tentacles' functions and several children said they were for senses, to which Mario pointed out that snails do not have nose; and all children but Romeo agreed that snails do not have hair. The teacher acknowledged children's interventions, and asked them to be careful while drawing, making clear that the representation should be accurate:

> Teacher: And they do not have a nose, neither, very well, Aitor! Are you listening, Igor? Because, now, when you make the drawing, if you draw a nose, it is wrong, because snails do not have a nose.
>
> Original language:
> Mestra: E tampouco teñen nariz. Moi ben, Aitor. Igor, ti estás escoitando? Porque agora cando fagas o debuxo, si lle fas unha nariz, mal, porque os caracois non teñen nariz.

Children were given a blank sheet of white paper and a black pen. The teacher asked the children not to "paint" (meaning not to fill the drawing with colors), just "draw" one snail. She told children to be careful, as, unlike their usual practice of starting with a pencil, they would be drawing directly with an ink pen.

> Teacher. Each one of you is going to draw one snail, take your time, there is no hurry, all right? Understood? One snail. We are using a pen, directly. We are not going to paint, we are going to draw! We do not paint. We draw with a pen not with a pencil, so it [*the drawing*] would be ready [*to be included in children's portfolio*].
>
> Original language:
> Mestra: Cada un vai debuxar un caracol, tranquilamente, sen prisa, vale? Entendido? Un caracol. Vamos a hacer con rotulador, directamente.

> Non vamos a pintar, vamos a debuxar! Non pintamos. Facemos o debuxo con rotulador, non con lápiz, vamos a facelo, para que nos quede listo.

The emphasis on reexamining snail's body parts before representing it, as well as the consideration that the choice of using just a black pen is more appropriate for a scientific drawing of an ideal (model of) snail, than coloring the drawing, which would resemble real life coloring, reveal important assumptions made by the teacher about both the nature and the conceptual role of models in science. It shows the importance she attributed to descriptive representations in science.

5.3 DATA ANALYSIS

In this section, the overall data corpus and the tools developed for its analysis are presented.

5.3.1 Data Corpus

Data collection involved accompanying the classroom, recording the sessions and collecting children's drawings.

The total number of drawings examined is 531, from which 353 correspond to ECE1-L and 178 to ECE3-L. The transcripts of 30 sessions (31 hours of videotapes) were examined. Figure 5.1 shows the timeline of production of drawings. Each drawing series is identified with a code: a capital letter followed by a number. The letter S stands for drawings made in the course of the 'Snails project', and C for those made in the 'Clouds project'. The letter is followed by the task number (chronological order). It should be noted that children were asked to produce a greater amount of drawings in ECE1-L (18), than in ECE3-L (9).

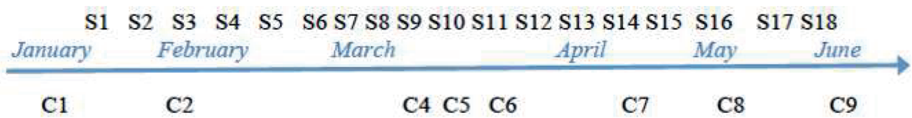


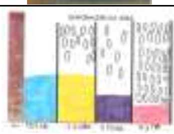
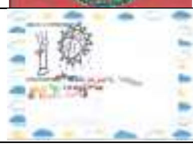
Figure 5.1 Timeline of the 'Snails' and 'Clouds' projects drawings. Upper row: snails' drawings (S1-S18). Lower row: cloud's drawings (C1-C9).

In order to illustrate the type of visual data analyzed, Table 5.3 includes a sample of each drawing task from ECE1-L and ECE3-L, accompanied by a brief description. The drawings analyzed in-depth are coded S1, S5, S6, S8, S17, C4, C5 and C6 and marked in bold in Table 5.3.

Table 5.3. Samples of children's drawings. Children's names in drawings S6, S11, S13, S17 and S18 covered with a circle, to protect their identity. In bold, drawings analyzed in-depth

Code	Experiment / concept represented	Example
S1	Children's first drawing of a snail's body	
S2	Experiment 'Smell', consisting of placing vinegar and water on both sides of snails, and observing their behavior for testing sense of smell. Snails went to the water	
S3	Experiment 'Hearing', consisting of comparing snails' behavior under silent and noisy conditions for testing sense of hearing. Snails behaved the same	
S4	Relation between the color of the food the snails ate and the color of the snails' poo	
S5	Experiment 'Taste', consisting of placing snails between salt and flour, and observing their behavior to test sense of taste. Snails went to the flour	
S6	Children's second drawing of snail's body	
S7	Experiment 'Surfaces', consisting of testing if snails could move over different surfaces, such as pins or sand	
S8	Snails' mouthpiece called radula	

S9	Picture book about snails 'The biggest house'	
S10	Snails' body parts discussed by children during their observations with a magnifying glass and the stereomicroscope	
S11	Race snail, main character of film 'Turbo'	
S12	Snails' reproduction: snails are hermaphrodite and can lay up to 100 eggs	
S13	Stereomicroscope used for carrying out observations	
S14	Land and sea snails' shells: children manipulated them and discussed their differences	
S15	Experiment 'Strength', consisting of testing if snails could carry potatoes	
S16	Experiment 'Balance', consisting of testing if snails could hang from cotton threads, nylon and wire.	
S17	Limpet's radula that children observed with the stereomicroscope	

S18	Animals that eat snails	
C1	First drawing of the sky	
C2	Experiment 'Boiling', consisting of observing boiling water in a kettle and placing a mirror above for condensation	
C3	Black/grey clouds have many water drops and white clouds have not as many	
C4	Recording the four measurements taken in a glass of water left to evaporate (experiment 'Evaporation')	
C5	Experiment 'Evaporation', consisting of leaving glasses and bags with water inside and outside the class and observing the changes for 3 weeks	
C6	Solid, liquid and gas state	
C7	Experiment 'Making a cloud', consisting of making a "cloud" (swirl of drops) inside a jar by pouring hot water and placing ice on the top	
C8	Water cycle	
C9	Experiment 'Making rain', consisting of "making rain" by condensing water drops on a cold surface	

5.3.2 Methods and Tools for the Analysis of the Drawings

In order to answer the first research question: *Which science meanings about snails are constructed and communicated by ECE1-L children in their expressed models and how do they change during the year?* the analysis focuses on two series of drawings from the 18 pupils (8 girls and 10 boys) (N=36 drawings), who handed both drawings. Two complementary analyses are carried out: a) comparative content (first and second series), which focuses in *what* is represented; and b) social semiotic analysis (second series), which focuses on *how* it is represented.

This set of data was chosen because: a) from all the drawings produced by children during the course of the science projects, these two series were the only ones with exactly the same focus, depicting a snail's body and its parts; and b) although there were 23 pupils in the ECE1-L class, only 18 children produced both series of drawings. These conditions allow us for comparison of both series of drawings through comparative content analysis, in order to examine changes in children's expressed models of a snail.

Table 5.4. Content analysis of drawings of snails: variables and values identified

<table>
<tr><th colspan="2">Categories of content variables</th><th>Values</th></tr>
<tr><td colspan="2" rowspan="4">Representation of the whole body</td><td>Anthropomorphic</td></tr>
<tr><td>Non Anthropomorphic</td></tr>
<tr><td>With limbs</td></tr>
<tr><td>Without limbs</td></tr>
<tr><td rowspan="10">Body parts represented</td><td rowspan="2">Eyes</td><td>With eyes</td></tr>
<tr><td>Without eyes</td></tr>
<tr><td rowspan="3">Tentacles</td><td>Not represented</td></tr>
<tr><td>One pair</td></tr>
<tr><td>Two pairs</td></tr>
<tr><td rowspan="3">Mouth</td><td>Anthropomorphic with teeth</td></tr>
<tr><td>Anthropomorphic without teeth</td></tr>
<tr><td>Radula</td></tr>
<tr><td rowspan="2">Helix</td><td>Represented</td></tr>
<tr><td>Not represented</td></tr>
<tr><td colspan="2" rowspan="2">Production of slime</td><td>Represented</td></tr>
<tr><td>Not represented</td></tr>
</table>

The two series of drawings of the snail were considered descriptive, that is, drawings that aim to represent the essence of what is represented (see Table 2.3 of the framework, adapted from Kress & Van Leeuwen, 1996). Within the descriptive type, they can be viewed as analytical, as the guidelines to perform the task, given by the teacher, were to represent a snail and its parts. In both series of drawings, the snail is depicted as being made up of a number of parts – for instance, snail's shell – which are the content variables (Bell, 2001). The content variables analyzed and their values are summarized in Table 5.4.

In order to answer both the first and second research questions, *Which science meanings about snails are constructed and communicated by children in their expressed models and how do they change?* and *Which communicative and representation resources of the science classroom community are appropriated by ECE1-L children?,* the second series of drawings of the snail (N=18), was submitted to social semiotic analysis.

Only the second series was analyzed due to limitations presented by the first drawings. The second drawing was not altered at all by the teacher and we were present at the time of producing it; whereas for the first one we were not in the class and the teacher intervened in the drawing, she cut the snail and the label with the name of the children; and pasted them to a new sheet. It should be clarified that in many occasions in ECE1-L, the teacher would intervene in children's drawings, for instance, by cutting and pasting them into a new card; writing labels, so that families would understand better the contents; or providing a template. Alterations of this type modify the potential meaning of the drawing, which is precisely what we aim to access to with social semiotic analysis.

These drawings were examined and, in interaction with the literature, a rubric of five types of semiotic resources was elaborated. In order to properly "read" the images, it was necessary to determine the orientation of the sheet of paper according to the combination of the information provided by the position of the tentacles (pointing up) and the slime (at the bottom); and the orientation of the letters in the children's name.

Table 5.5 summarizes the coding categories for the analysis: modality, position (interactive meaning), information value, framing and salience (compositional meaning). Coding categories are built by selecting the types of semiotic resources that are mobilized by children in these drawings, not by all possible semiotic resources defined in Table 2.3.

Table 5.5. Types of semiotic resources

<table>
<tr><th>Type</th><th>Resource Expression</th><th colspan="2">Definition</th></tr>
<tr><td rowspan="2">Modality</td><td>Scientific</td><td colspan="2">Representation of a model of snail – not a portrait of one of the snails from the box, but an “ideal” snail. Lack of decoration</td></tr>
<tr><td>Non-Scientific</td><td colspan="2">Representation of a particular snail. Drawing is decorated</td></tr>
<tr><td rowspan="2">Position</td><td>Predominantly Frontal</td><td colspan="2">Snail is heading towards the viewer: the snail’s tentacles are placed on a vertical axis (mostly on the upper part) with respect to the shell</td></tr>
<tr><td>Predominantly Side</td><td colspan="2">Snail is heading towards one side: the snail’s tentacles are placed on an horizontal axis with respect to the shell</td></tr>
<tr><td rowspan="3">Salience</td><td rowspan="3">Relative importance of elements</td><td>Oversized element</td><td>Element salient in size, not proportional to the rest of elements</td></tr>
<tr><td>Misplaced element</td><td>Element that cannot be seen the way it is represented from the chosen perspective</td></tr>
<tr><td>Saturation</td><td>Successive layers of black pen applied to one or several elements of the drawing</td></tr>
<tr><td>Information Value</td><td>Position of the image is centered or uses predominantly one of the sides</td><td colspan="2">How the elements are placed on the sheet: left, right, up</td></tr>
<tr><td rowspan="2">Framing</td><td>Separation of elements</td><td colspan="2">There are elements of the image that are disconnected, for instance, name and drawing</td></tr>
<tr><td>Relative positions among related elements</td><td colspan="2">Relative positions between slime and body, for instance, and orientation on the sheet</td></tr>
</table>

In the second column we introduce a new coding, *resource expression,* corresponding to how each type of semiotic resource is used in these particular drawings. For modality, images were coded into scientific, a model of an ideal snail, lacking decoration; or non-scientific, representation of a particular snail, decorated. The position in which snails were represented was drawn according to the axis in which tentacles are placed with respect to the shell: vertical axis for the frontal one and horizontal axis for the side. Salience of elements refers to oversizing, misplacing or saturating given elements with several layers of pen. Information value was characterized according to the placing of the elements on the sheet (center, sides). Framing of the image refers to the relative placing of the depicted elements among them and to their separation.

In order to answer the third research question: *How do children's ways of engagement with scientific expressed models become increasingly more complex from ECE1-L to ECE3-L?* the analysis focuses on all the drawings (482) from the 21 children (8 girls and 13 boys) that remained both years in the classroom. From these, 321 correspond to ECE1-L ('Snails project', 18 drawing tasks) and 161 ('Clouds project', 9 drawings tasks) to ECE3-L.

A content analysis (Bell, 2001) was carried out. The following variables were identified: type of elements, type of drawing technique and use of color. The number of drawings that show a value within each variable (e.g. for the variable techniques, one value is tempera) in each task was registered.

The variable of analysis *type of element* draws from Bruner (1996), Gilbert (2004) and other studies discussed in the framework for the distinction between iconic and symbolic elements: iconic elements are those that physically resemble observable entities, for instance, the material and tools used in an experiment. Symbolic elements are those that do not physically resemble what they stand for, as they can represent either entities or relationships. Its meaning is given by an arbitrary code that has to be learnt in order to interpret them, for instance: an arrow, a shared color code, that express relationships among elements in the drawing; or they stand for not observable elements that are important for the phenomena represented: water particles in the air. Table 5.6 illustrates this analysis with examples from the drawings.

Table 5.6. Content analysis of drawings. 'Snails project' drawings: S number. 'Clouds project' drawings: C number

Variable	Value	Example from children's drawing
Element	Iconic	Material used in experiment 'Making a cloud', C7
	Symbolic	Lines of separation between land and sea snail, S14
Technique	Watercolor	Background in first drawing of snail, S1
	Tempera	Background in drawing of limpet's radula, S17
	Pen	Drawing of experiment 'Evaporation' , C5
	Wet Wax Crayon	Drawing of the sky, C1
Coloring	Black and White	Drawing of snails' radula, S8
	Color	Drawing of Turbo, S11

Due to the large number of drawing tasks over these two units of instruction, in order to answer the third research question, we selected six tasks from four children to focus on. From these, five tasks were chosen because they were produced in interaction with other modeling and representational practices and they serve to explore changes along the three years and a range of dimensions analyzed in the drawings. Fourteen drawings from the three focal students, which correspond to these five tasks, are analyzed. Another two drawings, from two of the focal students, are analyzed with the purpose of situating the context and children's ways with models and representations while engaged in the projects.

The focal children are those who handed all (one boy) or all but one (one girl, one boy) of the 27 drawings that the children were asked to complete. Other three children are representative of the class.

The first focal student, Aitor, is a boy. He is the only child that submitted all 27 drawings from first and third year of the study. He does not intervene much in the class talk, but when he intervenes he does it carefully, showing mastering of the contents and ease in relating class experiences to the subject of the discussion. The teacher has commented to the researcher, during the unstructured interview, that he is clever and shy.

Loreto is a girl. She handed in 26 drawings. She intervenes more than Aitor in the class talk, but not as much as other students, because she is often out-of-task, playing with other children.

Mario is a boy. He turned in 26 drawings. He intervenes very often in the class talk and frequently brings information from home. The teacher often asks him to be neater when drawing and to paint inside the lines.

5.3.3 Methods and Tools for the Analysis of the Transcripts

In order to answer the third research question, transcripts (30 sessions; 31 hours) were analyzed through prolonged immersion in the data. The transcripts were divided into episodes, corresponding to consecutive turns devoted to the same topic or action (Gee, 2005).

Episodes in which students were engaged in practices of use and production of expressed models and representations were identified. These practices were further examined and distributed according to types, drawing from Schwarz et al. (2009), definition of scientific modeling through the practice and the metaknowledge that guides it. According to them, the elements of the practice are: using, constructing, evaluating and revising scientific models. Drawing from Gilbert et al. (2000) ideas about the modes in which a model can be expressed, these practices were further distributed into the three semiotic modes in which the participants expressed the model: a) *visual mode*, which involves the use of graphical and pictorial forms; b) *concrete mode*, that we call *physical*, which involves the use of materials; and c) *gestural mode*, which involves action. It should be noted that we do not include all the types of practices and modes from Gilbert et al. (2000), but only those identified in the data (Table 5.7).

Table 5.7. Types of practices of engagement with expressed models and representations in the ECE-L classroom

Type of practice	Performance	Mode	Example from the classroom
Use of models	Children use a model, produced by them or by others, to illustrate, explain, and predict phenomena	Visual	Interpretation of an image (picture, drawing): snail's inner parts diagram (ECE1-L); symbols in the weather forecast map (ECE3-L)
		Physical	Interpretation and manipulation of the model 'Ecosystem': a greenhouse in which children plant seeds, pour water and observe its condensation and plant growth (ECE3-L)
		Gestural	Interpretation of the model of three states of water enacted by children with their body, relating their movement to each state, following teacher's instructions (ECE3-L)
Production of models	Children construct models consistent with prior evidence and theories to illustrate, explain, or predict phenomena	Visual	Production of classroom display: kind of food snails eat or do not eat (ECE1-L) Individual drawing of a snail (ECE1-L) or the sky (ECE3-L)
		Physical	Construction of stratus, cirrus and cumulus clouds with cotton (ECE3-L) experiment 'Making rain': condensation of water on a cold surface (ECE3-L)
		Gestural	Mimics to imitate snails eating (ECE1-L). Enacting the water cycle (ECE-3)
Evaluation of models	Children compare and evaluate the ability of different models to accurately represent phenomena	Physical	Comparison of what children can learn with each one of two models produced by them: clouds made by cotton and clouds made by convection current in the experiment 'Making a cloud' (ECE3-L)

5.4 Results: Changes in Science Meanings in ECE1-L Children' s Expressed Models of Snails

This section discusses the first research question: *Which science meanings about snails are constructed and communicated by ECE1-L children in their expressed models and how do they change during the year?*

Some of the drawings, discussed in detail here, include the child's name. Pseudonyms were given to the children and, in order to protect their anonymity, while keeping the information given by the presence and position of this label, names have been covered by an oval shape occupying the same position.

Table 5. 8. Comparative content analysis of dimensions represented in S1 and S6, snail's 1st and 2nd drawing, respectively. N=18

Dimensions			S1	S6
Representation of whole body	Anthropomorphic body		12	3
	Body with legs or arms		6	0
Body Parts	a) Tentacles	0 tentacles	4	2
		1 pair	11	7
		2 pairs	3	9
	b) Thicker end of tentacles (eyes)		1	12
	c) Mouthparts	Anthropomorphic mouth with teeth	5	0
		Anthropomorphic mouth without teeth	4	1
		Radula	0	3
	d) Helix		3	9
Production of slime			1	11

Table 5.8 summarizes the results of the comparative content analysis of drawings S1 and S6 from ECE1-L, completed in a period of one month, according to the three coding dimensions: representation of the whole body, body parts represented – further divided into four sub-sections: a) Tentacles; b) Eyes; c) Mouthparts and d) Helix; and production of slime.

Regarding the social semiotic analysis (only applied to the second series of drawings, due to the limitations discussed in the data analysis section), not every type of semiotic resource included in the Table 2.3 (framework section), was discussed. For instance, representational meanings were not object of analysis as, due to the teacher's instructions, all the drawings have a descriptive structure, and within these, analytical.

Table 5. 9. Semiotic resources mobilized by the children. N=18.

Type	Resource Expression		NºDrawings
Modality	Scientific		17
	Non-Scientific		1
Position	Predominantly Frontal (tentacles top/tentacles bottom)		8/1
	Predominantly Side (snail looking to the right/left)		4/3
	Unclear		2
Salience: Relative importance	Strategies for making something salient	Oversized element	14
		-tentacles	4
		-eyes	3
		-slime, radula (each one in 2 drawings)	4
		-body, shell, mouth, nose (three from each)	3
		Saturation	12
		-slime	6
		-helix, unknown elements (each in 2 drawings)	4
		-body, shell, tentacles (two from each element)	2
		Displaced element	3
		- slime	2
		- radula	1
Information Value	Drawing occupies the center of the sheet		15
	Drawing occupies mainly one area of the sheet (right/top)		2/1
Framing	Separation between some elements		17
	-child's name and snail (front/back)		14/2
	-several snails (horizontal/vertical disposition)		4/2
	-child's name and radula		1
	Relative positions among elements and/or on the sheet.	Child's name on the top/bottom	11/4
		Tentacles directed towards top of the sheet	14
		Slime underneath the body	8

The orientation of the sheet of paper was determined by combining the information given by the letters in children's names and the positions of tentacles and slime (horizontal, 12 children; and vertical, 6). Expression of the five types of semiotics resources presented in Table 5.5 was analyzed in detail and findings are summarized in Table 5.9.

First, we summarize the overall quantitative results of the 18 children that handed both tasks, and second we illustrate the results with examples from the drawings.

Results from both analysis about science meanings constructed by children in their representations are summarized, organized by the dimensions examined for the content analysis: representation of the whole body, body parts and production of slime.

Regarding the *representation of the whole body*, although the first drawings of snails were produced after observing them for two weeks, 12 out of 18 drawings represented anthropomorphic features, such as human-like face separated from the body, as seen in Sebastian's (Figure 5.2) and Ali's (Figure 5.4) first drawings. In contrast, only three of the second drawings are anthropomorphic, and examples of not-anthropomorphic representations are Sebastian's (Figure 5.3) and Ali's (Figure 5.5) second drawings. Six of the drawings in the first series represented legs or arms (see Figure 5.4), but none of the second series did so. Figure 5.2 shows a smiley snail with a human-like face: this model shows the influence of Sebastian's previous ideas, cultural and representational repertoires. Starting from that, and mediated by the experiences provided by the project, he developed a representation that included features that are more typically associated to scientific ones, for instance, profile view that allows for representing all the body parts studied (Figure 5.3). Ali's drawings (Figures 5.4 and 5.5) show a similar trend in the evolution of his model of snail. His first drawing (Figure 5.4) shows an anthropomorphic snail, with two pairs of limbs, whose face, with two tentacles on the top, occupies the proportions and place in snails' body later occupied by its shell (Figure 5.5). His second drawing resembles better the actual shape of a snail: proportions of shell and body, which are differentiated, number of tentacles and thicker end of one pair of them, a swell corresponding to the eyes.

Figure 5.2. Sebastian's first snail, S1

Figure 5.3. Sebastian's second snail, S6

Figure 5.4. Ali's first snail, S1

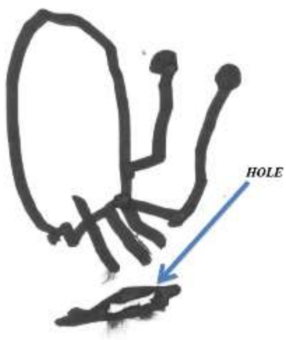


Figure 5.5. Ali's second snail, S6

Representation of *body parts*: *Tentacles* and *eyes* are important parts of snails' bodies, easy to observe. Snails have two pairs of tentacles. Although a majority of children represented tentacles both in the first (14) and second (16) drawing, in the first series only three drew the correct number, whilst in the second series there are nine drawings of a snail with two pairs of tentacles. Only one of the first drawings represented the thicker end of the tentacles, which corresponds to the eyes, whilst 12 of the second series did so (Table 5.8). The parts of snail's body highlighted in the second series, such as tentacles (4 drawings) and eyes (3 drawings) (see Table 5.9), had been the subject of discussion and experiments during the 'Snails project', as summarized in Table 5.2. Tentacles' functions were also identified by Internet search, eyes were observed and discussed; and snails' smell was the subject of an experiment. In 14 cases, tentacles are directed towards the top of the sheet, like snails' eyes when children got them out of the box. Only one child represented the tentacles pointing down. In Figure 5.3, the second drawing it can be observed that Sebastian represented the actual number of tentacles, including details such as the thicker end that corresponds to the eyes.

Mouthparts: snails have neither teeth nor tongue. As discussed in chapter 4 for ECE3-P, children found out, through purposeful observation and secondary sources, that, to eat, snails pull out a mouthpart, and that its name was radula: it is a thin and long, kind of rasping piece with hooked toothlets that allow them to scrape food and take it to their intestine. In nine of the first ECE1-L drawings, an anthropomorphic mouth was represented, in five cases with teeth (see Figure 5.2), similarly to first ECE3-P drawings discussed in chapter 4, while in the second series only one human-like mouth was represented (see Table 5.8). As analyzed in chapter 4 for ECE3-P and ECE1-L, when children observed and discussed the holes left in the food by snails, the teacher prompted them to observe snails' mouth in the class, sometimes using tools such as a stereomicroscope, and to look for information about it. In the session when children made the second series of drawings, they had not yet observed a radula through a stereomicroscope, but they had consulted secondary information sources, such as the Internet, where they located photographs and videos of snails eating and pictures and drawings of the radula. Children made sense of a very specific concept, the radula, whose shape and functions were assimilated and incorporated to their corpus of knowledge about snails. Three ECE1-L children represented a radula in the second drawing (see, for instance, Sebastian's, Figure 5.3). Being placed inside the mouth, the radula cannot be seen in its entirety, so displacing this piece outside, like one child did, indicates, from a semiotic perspective, the child's aim to include it and highlight it as an important element in snail's body. In Sebastian's second drawing, all the elements, but the radula, are scaled in size: he highlighted also this piece by oversizing it.

The *helix* in the shell was represented in three and nine cases, respectively, in the first and second drawing. Andrea's second drawing (Figure 5.6) is an accurate model of snail for this age: it keeps the actual number of tentacles, the body and the helix, whose relative sizes are scaled.

Figure 5.6. Andrea's second snail, S6

The attempt at representing a more accurate model of a snail seems to be the reason why in five drawings from the second series there were elements saturated by successive layers of black pen, not to highlight, but as an attempt to improve the drawing. By improving, it is meant producing a drawing that meets the teacher's requirements more closely, such as including all of the snails' parts. It implies children's self-evaluation of their own representations. Due to this, in these cases, drawing successive layers was not considered as a semiotic resource, but information about the drawing process, so they are not counted in Table 5.9. In the process of producing the drawing, those five children revised their initial idea and corrected the representation successively by adding new layers of pen, in four cases drawing another snail or even in one case another two. For instance, Gabriel (Figure 5.7) drew two snails, the one on the right in more detail: the helix and the thicker end of the tentacles are represented and the slime is drawn underneath the body.

Figure 5.7. Gabriel's second snail, S6

Regarding the production of slime; there was a shift from 1 to 11 drawings representing it. In the second series, slime was highlighted in 10 cases, which indicates that children considered it an important feature of snails. They chose to highlight it by oversizing (2 drawings), saturating (6) or displacing it (2) (Table 5.9). The teacher reported that at the beginning of the project some children said that slime was disgusting, while at the moment the second drawings were made, all of them liked to touch the snails and to allow them to walk over their arms, talking about the slime they left while doing so. In eight cases, slime was placed underneath the snail's body from which it is segregated. Ali's second drawing represents a snail with slime underneath its body that was saturated to the point that the child broke the sheet, making a hole in it (Figure 5.5, hole indicated with a label and an arrow).

From these results, it can be seen that the majority of children chose to highlight some elements in their drawing. They did it by using different strategies as summarized in Table 5.9, either by oversizing them (14), by saturation (12) or displacing them (3). This means that they are acquiring a range of resources for their communication, in this case in order to highlight what they considered to be important. Being able to communicate with others and to express meanings is a relevant skill both in science and in daily life, thus the importance to provide children with opportunities to express themselves from early ages.

One of the children highlighted several parts we could not identify. Nevertheless, his choice of differentiating several important elements indicates that he saw the snail's body as made up of different parts.

A nose was represented and highlighted by oversizing it in the second series in one case: we interpreted that it was drawn in reference to an experiment carried out in the class, in which they learnt that snails had smell, which had been discussed during this same session (see Table 5.2). In the case of Sebastian, he does not represent a nose anymore in the second drawing, but the pair of tentacles responsible for the smell function (Figure 5.3).

Drawings show that children are appropriating of an array of resources that enables them to express in greater detail, by drawing, meanings that sum up the contents represented.

As a summary, it can be said that there is a trend from anthropomorphic models of snails, some of which present human-like mouth and limbs in the first series of drawings, to less anthropomorphic ones a month later. The second series of drawings incorporated observed parts, such as tentacles and eyes; and processes, such as the production of slime; and represented other parts more accurately, such as the snail's shell.

5.5 Results: Communicative and Representation Resources of the Science Classroom Appropriated by ECE1-L Children

In order to answer the second research question: *Which communicative and representation resources of the science classroom community are appropriated by ECE1-L children?* results from the social semiotic analysis of the second series of drawings of a snail by ECE1-L children are discussed. By communicative resources we mean those social semiotic resources that have a meaning potential determined by how children represent the snail. They are used by children to suggest and communicate meanings to the teacher and to their peers within the science class.

5.5.1 Identification and Production of Different Types of Tasks: Modality

Learning goals about contents and practices targeted in the 'Snails project' were mostly scientific, but the tasks the teacher designed also allowed children to develop abilities in different domains, such as plastic and visual arts, or languages. From the 18 drawings, 17 are coded in the scientific modality. As discussed in the methods section, drawings in scientific modality correspond to the criteria of: a) being a model of any snail, even if these models are not fully accurate in the sense that there are some of the body parts that they had studied that were missing; and b) being representations that lack a background.

Only one of the drawings (Figure 5.8, from Alberto) is coded as non-scientific. It seems to depict a given snail within a specific environment, or setting, as it includes background. It should be noted that Kress and Van Leeuwen (1996) pointed out that the way settings are represented it is important to realize the modality of the image. In other representation tasks during the project, children did draw backgrounds, mainly for producing artistic drawings. For this teacher, the aesthetics of children's drawings are very important. She asked children to produce neat drawings, sometimes encouraging them to decorate them. For instance, the teacher asked them to fill the background with colors when drawing a representation of a film about a race snail they watched; she also asked them to decorate blank sheets with colors of their own choice before she pasted in them children's drawings, for instance the first drawing of a snail. Alberto's choice to pay attention to the background was interpreted as his aim of decorating the drawing; whereas the other children's choice of not to draw any background, is interpreted as their aim to emphasize what a snail is. This suggests that children are acquiring the tools to recognize and represent the same content and modify its meaning depending on the context. That is a sophisticated skill related to metaknowledge about representation.

Figure 5.8. Alberto's second snail, S6

5.5.2 Establishing and Expressing Elements as Belonging to Different Categories

From the 18 children, 17 used different resources related to composition, such as separation among elements. This resource is used mainly to separate child's name and snail (16 cases) even by writing their name on the back of the drawing (2 of these cases). In the context of this class there are rules such as labeling productions that were positively valued. Name and drawing were separated as belonging to different ontological categories: the task itself and the class protocol of labeling with the name. The two children who wrote their name on the back made this distinction clear.

Another child, Alma, who was not still able to write, drew letter-like symbols (see Figure 5.9), separated from the snail's drawing.

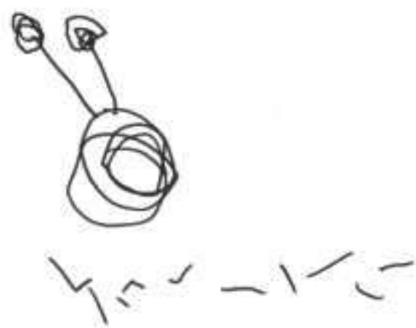


Figure 5.9. Alma's second snail, S6

One child drew the radula as a separated element, which might be because it is an important part of the snail for that child, but it cannot be seen from the outside.

Only one drawing, which corresponded to Alberto (Figure 5.8), that is not coded within the scientific modality, did not separate elements among them.

5.3.3 Appropriation of Written Communication

In Western culture, written messages are produced and read from left to right and from top to bottom. Children in ECE1-L were learning to read and to write, and every day in the school they were in touch with texts and labels, although by their first year of schooling most of them were only be able to write a few letters. The analysis of compositional resources indicates that children are appropriating written communication, as many children begin their drawings from left to right and from top to bottom, as discussed below.

The teacher's demands about the tasks involved placing the drawing in the center of the sheet and distributing elements (drawing and label) harmonically. This requirement was reflected on the data: 15 drawings are placed in the center of the page. Some children did not calculate accurately how much space they were occupying with their drawings and, as they were drawing directly with the black pen, they did not have the chance to erase. Most children that wrote their name centered on the front of the sheet did it on the top (11 cases) and 4 did it on the bottom. From the remaining three, two wrote it on the left side, where they start writing (for instance Ali's, Figure 5.5).

When drawing more than one snail (six cases), children separated them, either in a horizontal (four cases) or a vertical (two cases) disposition. From these six drawings representing more than one snail, and assuming that the most accurate ones were the latest being produced, the sequence in which they were drawn corresponded to left to right direction, like western writing, in two cases. From the remaining four drawings, the first was Raissa's, left to right, like her family language writing (she is of Arabic origin); the second Ariadna's, bottom to top, like consecutive lines in a written page; and the third Igor's, who represented three figures: the two on the sides are saturated, so it might indicate he started the drawing in the center, or nucleus of the information.

The fourth one whose sequence is not from left to right, shows no differences in saturation neither in the elements depicted. The snail on the right hand side is bigger, as the intention of the child may be to represent a child and his parent, so it does not inform about this topic.

As a summary of the results about this research question, it can be said that, through enculturation in the science class community, children had been in touch with an array of visual communicative resources that they use in their representation. Hence, they are able to communicate meanings regarding the modality of their production, relationships between the elements that they depict. The analysis also reflects that they are immersed in and appropriating written communication.

5.6 Results: Increasing Complexity in Children's Engagement with Models and Representations From ECE1-L to ECE3-L

This section discusses the results related to the third research question: *How do children's ways of engagement with scientific expressed models become increasingly more complex from ECE1-L to ECE3-L?* First, an overview of the quantitative results is presented and then results from the in-depth analysis of children's drawings are discussed.

5.6.1 Overview of Children's Engagement with Modeling and Representational Practices

This section begins by addressing the types of modeling practices children were engaged in and how they evolved from ECE1-L to ECE3-L. From the analysis of the transcripts, it was found that in 27 out of 30 recorded sessions, from both ECE1-L and ECE3-L, children were engaged in three types of modeling and representational practices: using, producing and evaluating models, as summarized in Table 5.10. It was also found that there was an increase both in the number and the complexity of practices. Regarding the number of practices, it has to be noted that there are less recorded sessions in the first year. During this first year the children engaged mostly with models expressed in visual mode, whilst by the third year they engaged in a greater variety of modes. With reference to the types of practices, in both years children used and produced models, whilst they evaluated models only in the third year and only once.

Table 5.10. Discourse related to each type of modeling and representational practices in the transcripts. Mode of expression between brackets: visual (v), gestural (g) and physical (p)

Year	Using	Producing	Evaluating
ECE1-L	8 (v)	4 (v); 1 (g)	-
ECE3-L	12 (v); 5 (p)	7 (v); 4 (g); 8 (p)	1 (p)

During the first year of school, children put great effort and needed high intensity of scaffolding by the teacher –analyzed in chapter 7– in order to interpret representations, which presented difficulties for them, as for instance in the vignette discussed in the context section, in which Mario struggled to use the diagram of snail's inner organs, and had to be supported by the teacher.

In the third year, children were proficient at using and interpreting representations in a diversity of semiotic modes: visual, gestural and physical. This point can be illustrated with a vignette from ECE3-L, in which children were discussing a poster about the water cycle. The poster combined iconic elements, such as drawings of clouds and trees, and symbolic elements, such as a color code for the water drops.

> Teacher: How do you know these drops are vapor and those drops are [*liquid*] water?
> Romeo: Vapor... eh... is lighter [*colored*] than drops.
> Aitor: And they [*the drops*] go down turned the other way round.
> Mario: It [*the poster*] is to see... what real droplets do.
>
> Original language:
> Mestra: Por que sabedes que estas pingas son vapor y estas auga?
> Romeo: El vapor... eh... es más claro que las gotas.
> Aitor: Que... que... que bajan al revés.
> Mario: Es para ver cómo hace...para ver cómo hacen las gotitas de verdad.

In this excerpt, children refer to water particles as "drops". It should be noted that the term "particle" was brought from home by Ariadna. It was contained in a piece of information about clouds formation that she read to her classmates. In sessions 17 and 18, the term was introduced by the teacher in the context of discussing the experiment 'Making a cloud'. In session 18 one of the children made use of the term "fire particles" (original language: "partículas de fuego") to name the ashes originated when the teacher burnt a match in the course of the experiment. This experiment consisted in observing a swirl of water drops to go up and down along the height of a kettle, caused by a temperature gradient created by putting ice on the top and warm water on the bottom. The second time the experiment was carried out, the teacher threw a burning match inside the jar. The ashes provided a surface that favored the condensation of water drops, making them easier to see than when the experiment was carried out without a match.

When interpreting the poster, Aitor says that the drops go down "turned the other way round": he is referring to a symbolic code – tear shaped drops with the tip pointing up or down – used in the poster they in order to represent water particles going up as vapor or going down as rainwater.

Children also used this code in their own representations of the water cycle, drawing C8, from which a representative example, by Loreto, is reproduced here (see Figure 5.10). In these series of drawings all the children depicted symbolic elements, such as tear-shaped drops; and iconic elements of their choice, related to the water cycle, such as trees, clouds, or the Sun. All but two used the same color code, indicated by the teacher: evaporating water drops were painted in blue, and with the tip pointing up, and those evaporating were painted in red and "turned the other way round", as expressed by Aitor. The remaining two children used a colors of their choice to distinguish precipitating and evaporating water drops.

Figure 5.10. Loreto's water cycle, C8

In ECE1-L, the children produced more drawings, during 18 tasks, than in ECE3-L, during 9 tasks, due to the teacher's demands – it should be noted that Table 5.10 only summarizes those drawings produced in the recorded sessions. This type of practice, producing models, is further discussed in the next section, in which the in-depth analysis of the drawings and their increasing complexity are discussed.

Regarding evaluation of models, by the third year children engaged in metaknowledge talk, comparing the purpose and features of different models of the same phenomena. In session 25, children discussed whether the clouds they made out of cotton (see Figure 5.11) were useful to know how clouds look. They compared these cotton clouds to others made out of water through the experiment 'Making a cloud' (see Figure 5.12).

Mario said that the cloud they made with water was more similar to real clouds than the cotton cloud and Igor supported this idea:

> Igor: Because... in the drawing... there is only cotton, no water. And in the kettle, there is water, so we made a real cloud.
>
> Original language:
> Igor: Porque... en el dibujo... solo hay algodón, no hay agua. Y en el jarro hay agua, y sí que formamos una nube de verdad.

It should be noted that children pasted cotton on a blue paper card, which Igor referred to as "drawing". David, nevertheless, preferred the cotton clouds:

David: Because they were similar to… real clouds.

Original language:
David: Porque eran parecidas a... a las nubes de verdade.

Figure 5.11. Cotton clouds

Figure 5.12. Experiment 'Making a cloud'

The teacher prompted children to explain what they learnt with and what the purpose was for the cotton clouds:

Igor: In order to know how the clouds are.

Original language:
Igor: Para saber como son las nubes.

In the third year, they also engaged in discussions about how they could represent phenomena with a drawing and how the features of a given drawing conveyed a meaning about the phenomena represented. For instance, when children were asked to represent the four different measures of water in the glass from experiment 'Evaporation', registered during several weeks, drawing C4, Aitor suggested to his peers to draw a greater amount of drops in the air to represent a greater decrease in the height of water in the glass (Figure 5.13).

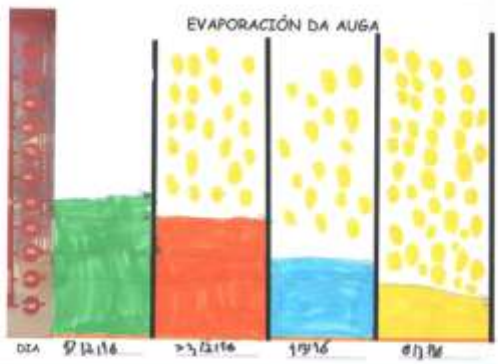


Figure 5.13. Register of measures of water in a glass, C4, by Aitor

This drawing represents a process that took several weeks to happen. In order to represent this process, many symbolic elements are used. We consider them symbolic according to the criteria discussed in the methods section: either because for their interpretation it is necessary to know a shared code (four columns and four dates) or because they represent non-observable elements (water drops in gas state). In session 14, children were reviewing the drawings and explaining the meanings conveyed in them:

Teacher: What was this graph?
David: From the… water that went down.

Original language:
Mestra: De que era esta gráfica?
David: De laa... agua que bajó.

David explained that the drawing represents "the water that went down", that is, the decreasing height of water in the glasses along several weeks. Next, the teacher questioned children about the data collected in the course of the experiment. It should be noted the importance given by the teacher to gather data and register them, for instance, with drawings:

Teacher: And what happened to it [*the water*]?
Gabriel: Eeh… it evaporated.
[…]
Teacher: A week later, we measured the [*height of water in the*] glass again… and, again, it…
Gabriel and several children: Went down.
[…]
Teacher *[pointing to the orange and blue columns in the drawing*]: Which one went down the most? Here or here?
Gabriel and David [*pointing to the drawing*] There, there.
David: There, in the blue one.
Gabriel: Noooooo in the orange one.
Teacher, That is difficult to know, right?
Gabriel: In the orange one.
Several: In the blue one.
Teacher: And why, Romeo?
Romeo: Because in the blue there is less [*the height of the column is lower*] and in the orange there is more…
[…]

Original language:
Mestra: Y que lle pasou?
Gabriel: Eeh... que se evaporou.
[…]
Mestra: Outra semana despois, volvimos a medir o vaso... y volveu a...?
Gabriel e outros nenos: Baixar.
[…]

Mestra *[sinalando]*: Cal baixou máis, aquí ou aquí?
Gabriel e David *[sinalando]*. Ahí, ahí.
David: Ahí, en la azul.
Gabriel: Nooo en la naranja.
Mestra: Eso é difícil de saber, eh.
Gabriel: En la naranja.
Varios: En el azul.
Mestra: Y por que, Romeo?
Romeo: Porque en el azul hay menos y en el naranja hay más... más...

Then, the teacher took David's drawing and showed it to the children and asked him to explain its meaning:

Teacher: David, you… here [*pointing to David's drawing*]… what did you do? Tell us.

David: That… in each [*imperceptible*]... as here [*pointing*] as here it evaporated… as here it evaporated a few [*drops*]… I put a few droplets. Here, as it evaporated a little more [*imperceptible*], more droplets… and then here, that evaporated much more… I put more drops here.

Original language:
Mestra: David, ti... aquí... que fixeches? Cóntanos.

David: Que... en cada *[imperceptible]* como aquí *[sinala]*... como aquí se evaporó... como aquí se evaporó pocas... puse poucas gotitas. Aquí, como se evaporou un pouco máis, *[imperceptible]* máis gotitas... e logo aquí, que se evaporou mucho máis... puse máis gotitas aquí.

It should be noted that all the contents included in drawing C4, but the drops, who were Aitor's suggestion as discussed above, were decided by the teacher. Still, children were able to discuss and fully interpret their meaning. This was not the only episode in which this happened. For instance, the teacher gave them a round piece of paper to draw the water cycle. Romeo explained that the drawing, C8 "[*it is round*] because the water cycle is repeated all the time" (original language: "Porque el ciclo del agua se repite todo el rato") (see C8 in Table 5.4).

About the mode in which models were expressed, in ECE1-L the children mainly used and produced visual models, with the exception of the gestural mode for imitating a snail eating. In ECE3-L the visual mode was still predominant: 19 out of 18 episodes of modeling practices implied the use (12) or production (5) of models expressed in the visual mode. Children also produced models in gestural (in 4 episodes) and physical (in 8) modes; and evaluated physical models in one occasion, as discussed above.

Regarding children's production of representations, the main findings from the content analysis of the drawings are summarized below: what children represented and how their drawings changed (Table 5.11). In order to know whether the decisions about including or not certain elements in their drawings were taken by children or by the teacher, we used data from the transcripts and complemented the information, when necessary, through interviews with the teacher.

In the first year the children color symbolic elements introduced by the teacher, such as arrows, separation lines or labels. In the third year, children spontaneously drew and proposed to their peers a variety of symbols, such as labels or color codes, and represented non-observable entities, like water drops in the air in the drawing C4, discussed above.

Table 5.11. Summary of content analysis: changes in children's representation from ECE1-L to ECE3-L

Dimension	ECE1-L	**ECE3-L**
Elements	Iconic: -More introduced by the teacher and less spontaneously used by children -Detail: some body parts missing; accuracy increases along school year	Iconic: - Less introduced by the teacher and more spontaneously used by children - Detail: small body parts are included; more accurate
	Symbolic: - All introduced by the teacher	Symbolic: - More used spontaneously by children and less introduced by the teacher
Use of color	- Mostly realistic coloring for scientific focus, more coloring for artistic drawings - Decisions mostly taken by the teacher	- Mostly realistic coloring for scientific focus, more coloring for artistic drawings - All decisions taken by children
Techniques	- Marker pen, pen, tempera, watercolor, wax crayon	-Marker pen in all but one: wet wax crayon

Children's attention to the detail in iconic elements increased with time. Along ECE1-L there was an evolution in the representation of both humans and snails, including new body parts and higher accuracy. In the last drawing of the first year (S18, see Table 5.4) children drew insects in great detail, for instance representing their six legs. Differences between ECE1-L and ECE3-L are significant: humans in ECE3-L always have a body if there is room for representing it, whilst in ECE1-L they may only have a head, even when having space. In ECE3-L there was a greater frequency of representation of small parts of the body, such as eyelashes and fingers. In ECE3-L, children also represented in great detail many elements: for instance, numbers marked in a glass, or the clothes that the teacher and the researcher were wearing.

The use of color was different according to the focus. Drawings in which the focus was scientific, as depicting experiments, tools or the features of a phenomena, for instance, the stereomicroscope, S13 or the experiment 'Making a cloud', C7, have a lower variety of colors than artistic ones, for instance, drawing of a picture book, S9 or of the sky, C1. Children mainly chose realistic colors for their scientific drawings, whilst for artistic ones they preferred any colors they like. This is especially relevant in ECE3-L, as the teacher did not constrain children's decisions about how many colors to use. However, a majority of children did not use much coloring in the scientific drawings. There are exceptions, such as the drawing of the water cycle, C8, which represents a scientific concept and is very colorful.

About the techniques, all children used the same one for each of the drawing tasks (e.g. all C1, were made using wet wax crayon), and there were a greater variety of techniques in the first year, as the teacher aimed to provide children with opportunities to master different ones. For the third year, children mostly used marker pen, a tool chosen by the teacher that allowed them to draw with more precision.

As a summary it can be said that children's engagement with modeling practices becomes more complex with time, engaging in a higher variety of them with greater ease and autonomy. This higher degree of autonomy is also reflected in the production of drawings: whilst in ECE1-L they did not make that many choices about what to represent and how to do it, in ECE3-L they are given much more room to represent their understandings their way, and still are able to complete the tasks.

5.6.2 Increasing Complexity of Children's Drawings

In this section the in-depth analysis of selected productions, in chronological order, is discussed.

The first drawing discussed is the representation of the experiment 'Taste', S5 (Figures 5.14, 5.15 and 5.16), which represents the third experiment carried out in ECE1-L towards the end of the first month of the project. This experiment seeks answering the question *Do snails have taste?,* discussed in chapter 4. The experimental procedure involved placing salt and flour at both sides of snails and observing their behavior. When snails went to the flour, they ate it. When approaching the salt, they turned back. Children interpreted these pieces of evidence as a confirmation of snails having the sense of taste.

The template for representing the results of this experiment in ECE1-L already contained the elements that made up the drawing, so students' choice was limited to color with hard wax crayons and to decorate the parts that the teacher had left for them to complete. As shown in the drawings in Figures 5.14, 5.15 and 5.16, children chose different colors to decorate snail, salt, and frame and to highlight the conclusion. Their choices differ: Aitor (Figure 5.14) and Mario (Figure 5.16) used colors that resemble those from the actual packet of flour. Aitor used a variety of colors for the snail, while Mario also chose those closer to real snails. Loreto (Figure 5.15) used two colors for the snail and one for the flour. Mario and Loreto decided to decorate the frame alternating colors, while Aitor preferred to repeat some of the colors in a line. They all meet the class requirements for aesthetically pleasing drawings: coloring inside the lines. The three children use only one color for highlighting the conclusion.

Figure 5.14. Aitor’s drawing of experiment ‘Taste’, S5

Figure 5.15. Loreto’s drawing of experiment ‘Taste’, S5

Figure 5.16. Mario’s drawing of experiment ‘Taste’, S5

This task allowed children to become familiar with and to use symbolic types of content, which is one of the pedagogic goals of the teacher. Symbolic contents in this production are: color codes, such as coloring the snail and the flour, but not the salt; to highlight the conclusion with a color; to use an "x" to cross out the salt (that the snails don't like); and to draw over the line that represents a path which leads the snail to the flour, but not the one leading to the salt.

About the texts in the drawing, the words that made up the conclusion "snails have the sense of taste" were given to the children, and they chose the order in which to paste them in the large group (class) discussion: all the children pasted them in the same order. The teacher asked children to write down the name of both salt and flour underneath each. This requirement meets two goals: practicing writing and identifying elements with labels, which is constantly demanded by the teacher in science productions during the first year. It can be observed that the three children have different ease to write, as this is a skill they are learning in their first year of schooling, and in some cases the teacher wrote again the word underneath the label, so that the families could understand it.

Children's exploration of snail's radula, discussed in chapter 4, illustrates how children learned and represented domain specific contents along the project.

The drawing of the snails' radula (S8) (Figures 5.17, 5.18 and 5.19) was made at the middle of the second month of project (February), after observing images of radula from the Internet, but not the radula itself. According to her targets for science representations, the teacher demanded the children to draw the radula without coloring it. She asked the children to write two labels: their name (to identify their production) and *radula* (title, to identify the content), using black pen on a blank sheet of paper. She also provided them with an opportunity for expressing themselves in an artistic way and to use different painting tools, by asking them to decorate a card with tempera. Afterwards, she cut out the radula and the labels and pasted them on the decorated card, in order to achieve an aesthetically pleasing production, which children brought home in their individual portfolio.

Figure 5.17. Aitor's drawing of snail's radula, S8

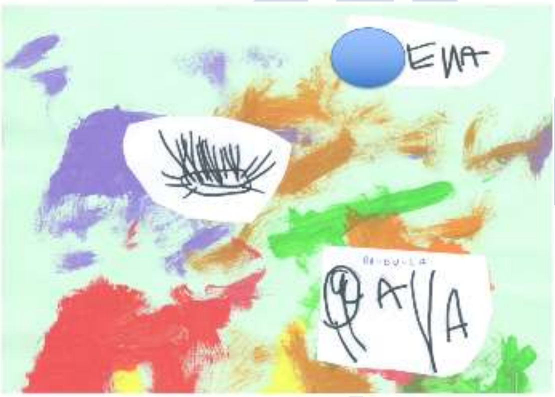


Figure 5.18. Loreto's drawing of snail's radula, S8

Figure 5.19. Mario's drawing of snail's radula, S8

At the beginning of the fifth month of the project (May), the researcher brought a dead limpet to the class in order to dissect it and to show its radula to the children, projecting it by means of a stereomicroscope and taking pictures of it. Two weeks later, the children discussed the pictures of the radula and the teacher asked them to represent it.

This drawing of the limpet's radula corresponds to S17 (Figures 5.20 and 5.21, Mario did not hand in this production). The teacher's instructions were similar to those for the snails' radula, S8. She asked the children to draw it with a black pen on a separate blank sheet; and to write the labels *limpet's radula* (*rádula de lapa*) and their name. Children decorated a card, using watercolors. Afterwards, the teacher cut out and pasted the drawings and labels into the card.

The children's names in these five drawings (only a few letters are shown to protect their identities) are more clearly written than "radula", because their name is the first word they learn to write. This is a task that is scaffolded by the teacher and repeated all along the school year. Evolution in writing along the school year is evidenced by these two series: the word *radula* and especially children's names are much more clearly written in the second one.

Figure 5.20. Aitor's drawing of limpet's radula, S17

Figure 5.21. Loreto's drawing of limpet's radula, S17

These two series of drawings, show how the two practices of a) using first- and second-hand data (discussed in chapter 4); and b) using and producing and models, interact in the construction of a concept.

Two years later, in ECE3-L, the children were engaged in the 'Clouds project'. During the four first sessions of the project, children had accepted the idea that clouds were made out of water, brought up by two pupils who attended a science workshop outside the class. While observing the actual clouds in the courtyard and the pictures of clouds in the class, they pointed out that grey and black ones were "for rain" while white ones were not. Children wondered, though, "how does water get to the clouds? "

In order for them to observe the evaporation process, the teacher designed, with little input from the students, the experiment 'Evaporation'. It consisted of pouring water into two plastic glasses and two airtight bags. One glass (open) and one bag (closed) were left inside the class and one of each outside. Water level was measured and marked in each, as seen in Figure 5.13, register of the measures. For three weeks (sessions 5 to 14), children observed, registered and discussed changes inside the glasses and bags.

The greatest difficulty encountered by children to explain water drops on the bags' walls and decrease in the height of water in the glasses was accepting the existence of a process that was not observable through the senses. Children accepted without problem that there was change from liquid to gas while carrying out the experiment 'Boiling', which involved evaporation at boiling temperature. In the course of this experiment, they were able to see the bulk of steam going out from the kettle and also saw and touched the water drops that were formed on the mirror placed over the steam. After this experience, they started to accept that, somehow, water was able to "go to the air" in the glasses and bags of the experiment 'Evaporation'. In session 14, when they were engaged in explaining their own representations of the register of measures from experiment 'Evaporation', drawing C4 (Figure 5.13), one child pointed out that the (evaporated) water drops represented were "very little".

For making the drawing about experiment 'Evaporation', (drawing C5), children used a black marker pen. The content analysis indicates that all of them have a conclusion, using slightly different wording. In the discussion that took place prior to the production of the drawings, the teacher asked the children which conclusion they could write, to which several children answered "The water evaporated". Loreto (see Figure 5.23) uses the present perfect tense "the water has evaroated (sic)" / "el agua se (h)a evaroado (sic)", while Aitor (Figure 5.22) and Mario (Figure 5.24) used the past tense, respectively in Spanish and Galician "the water evaporated" / "a auga se evaporou". These differences show that they are using their own terms in the interpretation of the changes in the glasses and bags, rather than using wording provided by the teacher, as was the case in the first year.

Regarding the analysis of content represented, all the 18 drawings depicted a kettle with water and drops, either going up to the air from the kettle or outside in the air. The three focal children depicted things that are not visible to the eye, such as the steam coming out from the glass (see Figures 5.22, 5.23 and 5.24). Aitor (Figure 5.22) and Mario (Figure 5.24) also depicted the drops going up from the bulk of water in it. It is worth noting that Mario filled all the space in the page with drops, representing the water in the air. It can be observed that the symbols used for representing drops vary from child to child: Aitor shaped them like tears when coming up in the glass from the liquid water, while when he depicted them outside the glass he did it as thick steam. Both Loreto (Figure 5.23) and Mario represented liquid water with lines and as separated round (Loreto) and tear (Mario) shapes in the gas state. Aitor represented the lines they marked on the glass walls for measuring its height as horizontal dashes outside the glass: measures are important in science and these were the data gathered by children to follow changes. All these individual differences in the drawings in the third year provide evidence of increased sophistication in children's use of symbolic elements.

Figure 5.22. Aitor's drawing of experiment 'Evaporation', C5

Figure 5.23. Loreto’s drawing of experiment ‘Evaporation’, C5

Figure 5.24. Mario’s drawing of experiment ‘Evaporation’, C5

In the third year the teacher introduced the scientific terms solid, gas and liquid, once children had carried out the experiments ‘Evaporation’ and ‘Boiling’. In session 8 of the ‘Clouds project’, children and teacher enacted with their bodies the experiment ‘Boiling’, introduced as a simulation game (Figure 5.25). The teacher made a circle on the floor with a wire, which stood for the kettle, and children acted as liquid water drops moving slowly in it. The teacher clapped to indicate temperature’s increase inside the kettle. Every time she clapped, children moved faster and faster. The collisions between them pushed some children outside the circle: they “became gas”.

Figure 5.25. Enacting the ‘Boiling game’, session 8

In the second month of the ‘Clouds project’, session 15, the teacher introduced through a video the concept of the water cycle. In the discussion that followed, she prompted children to explain the states of water they knew. They explained that solid is “ice” or “snow”; that gas is “when it goes up”, using the word “evaporation”; and that liquid is “normal water” “for drinking”. In sessions 15 and 16, children enacted a simulation model for the three states of water, highly scaffolded by the teacher. Liquid water was enacted by children moving “as a train” around the class, adapting their path to the obstacles (Figure 5.26). In “solid state” children hugged each other very tight in groups and they had to move around the class (Figure 5.27). As it was more difficult because they needed to stay together, they moved slower than in liquid state and could not reach many places because of the obstacles. For the gas state, children were allowed to run fast around the class towards wherever there was free space, which they found fun, and asked for enacting it again (Figure 5.28).

Figure 5.26. Enacting ‘Three states game’: liquid, session 15

Figure 5.27. Enacting the ‘Three states game’: solid, session 15

Figure 5.28. Enacting the ‘Three states game’: gas, session 15

The complexity of both simulations differs in several dimensions. In the 'Boiling game' children represented liquid and gas, whereas in the 'Three states' they also represented the solid state. In the 'Boiling game' they interact with the teacher's actions, moving faster when she claps and they go out of the circle that represents the kettle. It means that this model conveys entities of different nature: a state variable, the temperature, with which children interact, as it determines their behavior; and an object, the kettle, inside of which they move; and the molecular models of liquid and gas they are representing.

Drawings of the three states, C6, were produced in session 16. The teacher's instructions were: "Each one of you is going to draw on the place for the solid [*one of the three columns in which the sheet of paper was divided*], how the molecules would be placed" (original: "cada un ... vai a dibuxar no espacio do sólido como estarían as moléculas colocadas"). The children answered: "Together". Teacher: "Gas?", Children: "A bit more separated", "Running very fast". The responsibility of providing suggestions about how to represent the water states was left completely to the children. In all the drawings gas molecules are distributed all over the place.

The order in which the three states were represented differed, as it can be seen in the selected drawings (Figures 5.29, 5.30 and 5.31). The order was not considered a key factor neither by the teacher, who did not give instructions about it, nor by the children, because the focus of the representation was differentiating the three states. The order in which these were represented was children's choice.

Most children represented drops with a round shape in the drawings of the three states, for instance two of the focal students Aitor and Loreto. There were four children who did it with a teardrop shape, like Mario. Both types of symbols come from the representations used in the class, such as books or the poster of the water cycle. Two children used the teardrop shape only for one of the states (liquid and gas, respectively) and represented the remaining two (that is gas and solid; and liquid and solid) with a round shape. Children represented liquid molecules in a row, either open or closed with straight or round shape, as in Figures 5.29, 5.30, and 5.31.

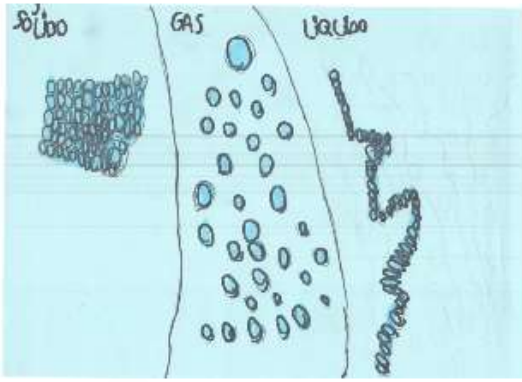


Figure 5.29. Aitor's drawing of the three states, C6

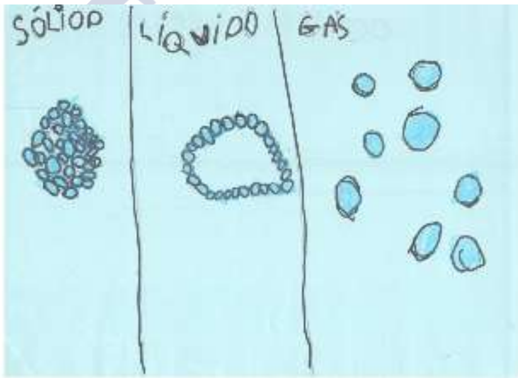


Figure 5.30. Loreto's drawing of the three states, C6

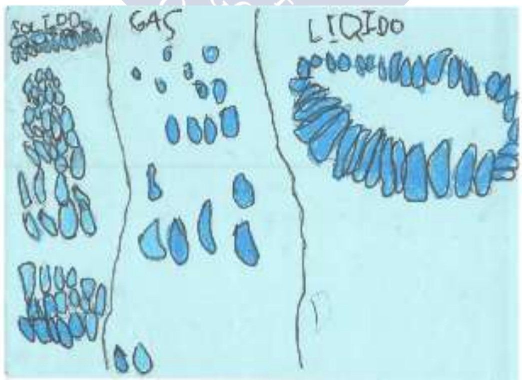


Figure 5.31. Mario's drawing of the three states, C6

Four children represented more than one time a solid state, for instance Mario, who represented it three times. All but two represented the solid state as a round figure: see the differences between Aitor and Mario (squared) and Loreto (round). There was also one child who differentiated the three states according to the distance between molecules, rather than to their disposition in space.

As a summary, it can be said that children's representations became increasingly more complex over time in the course of the three years studied. With time, children represented in more detail the scientific contents that they were learning, including non-observable elements. There is higher degree of variety of elements represented in their productions, as they become increasingly more autonomous and responsible for taking the decision about what to represent and how to represent. By ECE3-L children spontaneously included a greater number of symbols, whereas in ECE1-L, these symbols were suggested by the teacher. All these changes are discussed in the next section. Their drawings show other gains in addition to those related to science contents, such as improvement in writing skills and awareness of aesthetics.

5.7 DISCUSSION

This chapter aims to add to existing literature an examination of how young children engage in modeling, which is recognized both in the OECD (2016) and NRC (2012) frameworks as one of the three main areas of practices in science, in Early Childhood Education, ECE, an educative level that has been understudied in comparison to others. This chapter examines children's engagement with models and representations from ECE1-L to ECE3-L. On the one hand, it examines in depth how children construct and represent meanings about scientific concepts, and how, by doing so, they reveal their appropriation of communicative resources from the classroom. On the other hand, it is also concerned about the overall picture, examining how children's engagement with modeling practices and representations becomes more complex along the three years of ECE, in several dimensions. For instance, the variety of modeling practices they engage in is greater in the third year; and they become proficient at interpreting and including symbols in the representations. These and other dimensions of increased complexity are discussed at the end of this section.

In this study, two types of analysis, comparative content and social semiotic analysis, are used to address the first research question about meanings expressed by children's drawings. The interpretation of data from both perspectives allows for a deeper interpretation of drawings. Comparative content analysis also reveals changes in children's models, as it was used to compare two series of drawings of a snail made within a month of difference in the first year.

Children's drawings in ECE1-L represent parts that are important features of snails' body, necessary to define what a snail is, which explains why some of them have been highlighted by them.

The comparison between the two series of drawings from ECE1-L shows that even though children were already in contact with the animals since the beginning, some of these parts, like the two pairs of tentacles, were only perceived or modified after children were engaged in *purposeful observation* (Monteira & Jiménez-Aleixandre, 2016) of snails for several weeks. It is not just that children were given the opportunity to observe those snails, but that their observations were extended in time, recurrent, explicitly discussed and pursued a target, for instance, identification and description of snail's mouthparts. As Winner, Goldstein and Vincent-Lacrin (2014) point out, when helping children to develop the ability to observe (models, paintings, own and other children's drawings…) they apply their gains in their creations, improving them. According to these authors, observation is a critical ability, very important not just in experimental sciences, but also in other areas of knowledge, such as arts or social sciences.

Allowing the children to be close to the snails, manipulating them and pursuing answers to their questions had a positive effect in their curiosity for learning about the animal. It needs to be noted that all of the snail's drawings examined in this study are represented from a horizontal perspective from the viewer's point of view. From a semiotic perspective, this indicates that snails are not considered neither superior nor inferior by the children who drew them, but somehow familiar.

When representing science meanings about snails, the children used communicative resources. For instance, in order to highlight which parts of a snail they consider important to describe the animal, and thus to start building a model, children may increase its size and saturation, or to displace it. Not every child chose to highlight the same elements. Most children used resources related to composition, such as framing, in order to separate elements that do not belong together, mainly child's name and snail's representation.

The presence of saturation not with the purpose of highlighting, but to correct and improve snails' drawings – children were not allowed to delete as they were using an ink pen in the second series - shows that children as young as 3 and 4 year old are able to revise their own ideas. There are five drawings from the second series that present elements saturated by successive layers of black pen, not to highlight, but as an attempt to improve the drawing, due to which they were not considered a semiotic resource, but information about the drawing process. These attempts to improve the representation recall Pérez-Echeverría and Scheuer (2009) and Brooks (2005, 2009) ideas on interaction between external representations and mental models. In the process of producing the drawings, those five children revised their initial idea and corrected the representation successively by adding new layers of pen, in four cases drawing another snail and in one case two more snails. We agree with Brooks (2009) that the interaction of children with their own drawings promotes reflection about their own ideas. The ability of visualizing and revising models is of great importance both for autonomous learning and for science. Educational implications might be that, in order to provide children with chances to engage in revision of models, and to be able to support them, drawing tasks may be designed in order to achieve these opportunities and also in order to be able to know more about the processes that children undertake and in which way educators are able to support them best. As drawings are widely used in ECE, there might be necessary more studies about how they can be used as learning tools in the classroom, in line with Pérez-Echeverría and Scheuer's (2009) perspective, which conceives representations as learning tools.

Semiotic analysis allowed access both to the science meanings constructed and to other kinds of knowledge that students are constructing, such as the ability of choosing resources in order to communicate with others in different modalities. Children make use of protocols such as labeling the task, and they separated elements, differentiating two ontological categories: task and class rules. Social semiotics allows us to examine how certain cultural elements are incorporated in such a young age. For instance, Ali's drawing is placed towards the left hand side, where he starts writing. Even though Ali's family is of Arabic origin, his drawing reflects the school enculturation, as writing is a skill that children that are learning in this first year of schooling. Focusing in the placing, we can see that there are children who are already able to fully use a given space to develop a task, like Sebastian (Figure 5.3), while others like Andrea (Figure 5.6) have not yet developed that ability.

The analysis suggests that there are dimensions whose development goes in parallel. The fact of drawing an element that has not yet been observed, such as the radula, represented by three ECE1-L children in their second drawing of a snail, S6 (e.g. Figure 5.3), because it is an important feature that characterizes the snail, seems to be related to an emerging understanding about what a model is. The three children who drew the radula are the same ones that have interiorized more deeply aesthetic concerns acquired through their immersion in the classroom culture and exposure to an array of visual representations along the project. These three children reflected very well the class culture about aesthetics in terms of harmonic composition, distribution of elements along the whole sheet and balance between them. From these, Sebastian's drawing (Figure 5.3) is exceptionally harmonious, taking into account his short age, for this is a drawing made in his first year of schooling, and he was already able to manipulate the pen fluently and to draw according to aesthetic concerns.

Children's ways of engagement with modeling practices became increasingly more complex from ECE1-L to ECE3-L. We will discuss consecutively modeling and the specific practice of representation, although they are deeply intertwined. The increasing complexity has been found in these dimensions;

– More modeling practices, including evaluation, in ECE3-L and more sophisticated: Regarding the types of modeling practices, in

ECE1-L they used and produced models, whilst in ECE3-L they also evaluated models in one occasion, when they discussed and compared two models of a cloud. These models were the clouds made of cotton and the swirl of condensed water drops made in the course of the experiment 'Making a cloud' (Figures 5.10 and 5.11).

- Formulation of conclusions: in the first year, children did not formulate the conclusions included in their drawings of the experiments, whereas by the third year, children's formulated and wrote them on their own.

– Epistemic talk about how a meaning could be represented by drawings in ECE3-L: Children's talk about representations covered more aspects in ECE3-L than in ECE1-L. During ECE1-L they discussed the meaning of representations, often needing support from the teacher, interpreting them through class discussion. In ECE3-L they kept on interpreting representations through class discussion, but also engaged in discussing proposals about how a meaning could be represented through drawings. The teacher in this class considers talking science as central for children's learning along the science projects and she had been prompting the children to interpret their own and others' representations. She was insistent in her focus on questioning the children, so that they would engage in discussing these elements as a group. By ECE3-L children often engaged in talk about how and why we represent things the way we do spontaneously. For instance, David, talking about drawing C4, evaporation measures: "it [one of the columns] has more drops because it evaporated more".

Children's representations became increasingly more complex in the following dimensions:

– A greater diversity of semiotic modes in ECE3-L: in the third year there was a greater diversity of semiotic modes, such as visual, gestural and physical, in which models are expressed than in ECE1-L, when mainly visual, and once gestural were used. According to the NGSS (NGSS Lead States, 2013), modeling in grades K-2 includes using and developing models in diverse modes, diagrams, drawings, physical replica and dramatization, such as those enacted in this study. As Gilbert (2005) points out, visualization allows students to move within different modes of representation, and that makes it central to science education. Children in the study used and produced mostly visual models in ECE1-L, and by ECE3-L they had become proficient at engaging in modeling in a diversity of modes. Fostering the use of a variety of representational modes might be useful to reach most of the children, as diverse representational modes are incorporated which can account for children's diverse perspectives.

- Increased autonomy in the use of symbolic and iconic elements in drawings: children's ease to represent non-observable entities, such as water drops and to depict iconic elements in detail increases from ECE1-L to ECE3-L. The results from the content analysis show that in ECE1-L most of the iconic and all of the symbolic elements in children's representations were introduced by the teacher. In ECE3-L, children decided what to draw, both iconic and symbolic elements, and how to draw them, in the majority of their drawings. For instance, drawing S5 (Figures 5.13, 5.14 and 5.15), produced in ECE1-L, contains several symbolic elements: color code, union lines, which were decided by the teacher. In ECE3-L, children became more autonomous at including symbolic elements in their drawings. They decided which symbolic and iconic elements to draw in C5, the drawing about experiment 'Evaporation'. Each child took its own decisions about how to do it as shown by the differences between the shape of water drops evaporating and liquid water in the jar in Figures 5.21, 5.22 and 5.23. The symbolic elements in the drawing of the three states of water, C6, were decided by the teacher. She asked children to represent each of the three states of water in a different column. Even though the instructions about what to draw were very specific, she was not that specific about how to do it. Children's choices regarding the shape of the water molecules, their position and their coloring in each of the states differ (Figures 5.28, 5.29 and 5.30). Accuracy and attention to the detail in children's representations increased from first to third year. The increase in complexity from ECE1-L to ECE3-L can be closely related to teacher's scaffolding. Scaffolding is explored in chapter 7.

- Appropriation of shared visual codes to communicate to others: they started learning codes in ECE1-L. By ECE3-L they became autonomous at using and introducing their own ones. For instance, the teacher asked children to use a color code in order to distinguish among evaporating and precipitating water drops in drawing S8, representation of the water cycle: they were filled in red and blue, respectively. All children but two used this code, some of them with slight variations. For instance, one child drew the blue drops with a red edge and the red drops with a blue one. Two children created and used a color code of their own to distinguish the two types of drops.

– Shift from narrative drawings, including people, to conceptual drawings in ECE3-L: In the third year, when children autonomously decided which contents to draw in the experiment templates, the majority of children did not depict people involved in the experiments. For instance, from the 17 drawings of C5 examined, there were three children who decided to draw one, two and four people involved in the experiment. The “different case”, these three children, helps us to define and to better know the pattern: most children dedicated effort to produce a less narrative, more technical drawing, with “only” glasses and drops, enough to convey the meaning of evaporation, to interpret the phenomenon according to their class experiences. In Kress and van Leeuwen’s (1996) terms, these drawings belong to the conceptual category, whereas the first year drawings belong mostly to the narrative category.

In our analysis, there are several themes that came up in addition to the focus on scientific practices. For instance, affective indicators such as smiley faces in water drops is something we find multiple times across the data for instance in C6, or two smiling teachers with children that are sometimes represented in the documents. Also interesting is the role of color when children decide to use it, a decision which is based in the class culture they have been experiencing. Children mostly use black and white for technical drawings, while using many colors for the open-ended drawings. Sometimes, as in C1, they have limited color choices available to them but they used them all in their drawings.

For educational research is important to be able to access to science and cultural gains communicated by children. This chapter aims to give an insight on how scientific practices, and more specifically the practice of modeling, are enacted by children of such a young age. The other main aim of this chapter is to broaden existing knowledge about how young children represent their scientific and communicative gains through drawings. At these ages, children’s representations such as drawings are a powerful tool for communication, as drawing might be easier for young children than other semiotic modes, such as writing or accurate oral communication.

6 BUILDING SCIENTIFIC EXPLANATIONS ABOUT STATE CHANGES

This chapter addresses the third research objective: *To explore which are the features of building explanations in ECE3 and how this practice evolves along a school year.* First, the research questions are presented; second, the participants and context are described. Third, results are discussed.

6.1 INTRODUCTION

We aim to examine the ways in which children in the third year of ECE (5-6 years old) engage in building explanations. We seek to examine their features and evolution along a school year and how everyday and classroom experiences mediate their construction of explanations. This aim can be summarized by the following research question:

What are the features of ECE3-L children's explanations about state changes and how do they evolve along the school year?

6.2 PARTICIPANTS AND CONTEXT

The participants are the 23 children in the group of the longitudinal study, ECE3-L (13 boys, 10 girls; 5-6 years old), and their teacher. The study takes place the third year of the study, in the context of the 'Clouds project' that lasted for five months and whose design has been discussed in chapter 5. Prompted by the teacher, the children started to discuss their ideas about cloud formation. Two children, who were enrolled in after-school science activities, brought to the class the idea: "Clouds are made out of water". Children wondered, though: *how can water get to the clouds?* The teacher took children's questions as the starting point to introduce the phenomena of water state changes.

The group carried out four different experiments involving water state changes from liquid to gas under different conditions. They were repeated and reviewed several times along the project. Table 6.1 summarizes the experiments, including reworked versions, their procedures and the number of sessions devoted to carrying them out. The experiments are identified with the names used by the teacher and the children.

Table 6.1. Experiments about water state changes (reworked experiments between brackets)

Experiment (reworking)	Procedure	Sessions repeated
1 Evaporation	Leaving water in two closed airtight bags and two open glasses, inside and outside the window and observing changes. Registering the height of water in the glasses; discussing drops on the walls of the bags	1 (Bags and glasses were monitored along three weeks)
2 Boiling	Pouring water in an open kettle, heating it until boiling temperature and placing a mirror above. Observing evaporation and condensation	3
3 Making a cloud (3.1 without match & 3.2 with match)	Pouring warm water on the bottom of a jar and ice on the top. Observing a swirl of drops going up and down due to the temperature gradient created inside the jar. Two reworked experiments: 3.1, with and 3.2, without a match	3 (3.1) 2 (3.2)
4 Making rain (4.1 inside & 4.2 outside the physical model 'Ecosystem')	Observing condensation of water below the top of the game 'Ecosystem'. Two reworked experiments: 4.1) placing ice on the top of the model, so that the water in the air inside it condenses; and 4.2) taking the top of the model off and placing it over boiling water, so that the water flow is interrupted in its way up and condenses	1 (4.1) 2 (4.2)

The procedure for carrying out each of the experiments followed four steps: 1) children shared design proposals and predictions about what was going to happen; 2) teacher and children together set up the experiment; 3) they observed the experiment; and 4) children and teacher discussed their observations.

The first two experiments, 'Evaporation' and 'Boiling', were carried out in the large group and they were named by the teacher after children had observed and discussed them. The experiment 'Evaporation' involved state changes at room temperature; and the experiment 'Boiling', state changes at boiling temperature.

Before carrying out the experiment 'Evaporation', children were told they were going to learn how water could get to the clouds. The teacher presented the material, water and recipients. The children suggested leaving some water inside the recipients for an undetermined period in order to obtain a cloud. The teacher poured the water on the recipients and children marked its level with a pen. They checked the recipients and discussed the changes in them for the following three weeks.

The experiment 'Boiling' was entirely designed by the teacher. It was carried out collectively. Children measured a volume of water and poured it inside a kettle that was then heated until boiling temperature. The teacher placed a mirror over the kettle and children observed and touched the water drops condensing on its surface.

In the experiments 'Making a cloud' and 'Making rain', children encountered great difficulties in interpreting their observations, so they were carried out both in large (class) and small group (3-6 children). These experiments were realized following two different procedures each (see Table 6.1, experiments and reworked versions), which are explained next.

The third experiment, 'Making a cloud', was introduced by the teacher as "what do we need for making a cloud?" She introduced the material to the children: a jar, ice, warm water and a match. Children suggested pouring the warm water and, strongly scaffolded by the teacher, placing the ice on the top of the jar. A convection current was caused inside the jar, by pouring warm water on the bottom and placing ice on the top. Children observed the condensation of water drops on the jar's walls and a swirl of condensed water drops going up and down the height of the jar. The two versions of this experiment differed in whether the teacher did not (3.1) or did (3.2) introduce a burning match inside the jar. The match made easier to observe the "cloud" created in the jar, because the ashes from its combustion provided a surface for the condensation of the water drops.

The fourth experiment, 'Making rain', consisted in observing the condensation of water under the top of a physical model called 'Ecosystem'. This model consisted in a small greenhouse with a little pond in the middle in which children planted seeds. The first time this experiment was carried out, the teacher suggested that, instead of watering the plants, they could "make rain" inside following the instructions manual. According to these, the children placed ice on the top of the replica. The inner shape of the top of the apparatus favored condensation of the water drops in the air underneath. This is the reworked version that we identified as experiment 4.1 (Table 6.1). It was carried out in large and small group. The second and third time that this experiment was performed the procedure was different. The teacher heated water on a kettle, placed the top of the model above and opened the kettle. The water from the kettle condensed when it reached the top. This version is identified as experiment 4.2. It should be noted that this reworked version is similar to the experiment 'Boiling', in which children observed condensation of drops on the surface of a mirror placed over the kettle.

Table 6.2. Models about state changes enacted by children with their bodies

Name	Model	Sessions
Boiling	Children enact the experiment 'Boiling'. They are told that they are liquid water drops moving slowly inside a circle on the floor, which stands for the kettle. Each time the teacher claps means that the temperature inside the kettle goes up and children have to move faster, until eventually they collide and get out of the circle, becoming evaporated water	2
Three states	Children enact the three states of water: gas, they run all over the class; liquid, they move together in a line, avoiding obstacles in their way; solid, they hold tight all together and cannot avoid obstacles when moving around the class	2
Water cycle	Children enact the cycle of water. They first represent the river, going together in a line. When they are told by the teacher to evaporate, they separate and run around the class. When the teacher asks them to become a cloud and to rain, they get together in groups of two and then go back to the river position	1

Besides carrying out experiments, children represented the three states of water and state changes with the movement of their bodies. The teacher introduced these gestural models as simulation games. They were named: ‘Boiling game’, ‘Three states game’ and ‘Water cycle game’. The number of sessions in which they were repeated and their descriptions are summarized in Table 6.2.

Before enacting the models, the teacher explained to the children what they were going to represent and gave detailed instructions about how to represent it. Afterwards, children discussed what each way of moving and changing positions represented.

It should be noted that the models ‘Boiling game’ and ‘Three states game’, represent the kinetics of the molecules, as children change the speed they are moving to symbolize state changes; whilst all the three models represent the distance between water molecules in each state. The ‘Boiling game’ and the ‘Water cycle game’ include the representation of macroscopic entities as well, such as the kettle, a cloud and a river; whereas the ‘Three states game’ focuses only on representing water molecules, that children called “drops”. In this classroom, the terms *water particle* and *water molecule* were used by the teacher. The term *particle* was introduced in the classroom through a piece of information that a girl brought from home and it was used in school videos about state changes. Instead of using any of these two terms, children used the term *water drops*.

6. 3 Data Analysis

In this section, data corpus and tools for analysis are discussed. The analysis focuses on the transcripts from the third year of study (ECE3-L; 24 sessions; 27.5 hours).

6.3.1 Methods for the Analysis of the Transcripts

A thematic analysis of the transcripts was carried out, in order to identify themes recurring in more than one session. The themes identified are: *state changes*; *cloud formation*; *types of clouds*; *atmospheric phenomena* – from these, *rain* was the atmoepheric phenomena most frequently addressed –; and *water cycle*, as summarized in Table 6.3. From these five recurrent topics, state changes was the most recurrent theme, mentioned in 20 out of 24 recorded sessions.

Table 6.3. Recurring topics in several sessions in the 'Clouds project' (recorded sessions=24)

Topic	State changes	Cloud formation	Types of clouds	Atmospheric phenomena (rain)	Water cycle
Frequency	20	18	13	11 (10)	5

In order to answer the research question, 106 episodes from 13 sessions (sessions 5, 6, 7, 8, 11, 12, 13, 14, 15, 16, 17, 21 and 23) were selected and subjected to discourse analysis. These episodes and sessions were chosen because: first, they take place beginning in session 5, from which children started to explore state changes systematically; and second, children devoted these episodes to discuss, carry out experiments and model the phenomena involved.

A discourse analysis was carried out. Sessions were distributed into episodes, made of several successive turns of speech devoted to the same topic or action. The number of interventions of each child and the teacher in the discourse was recorded in order to account for their participation.

An explanation can be considered a model that is expressed in a verbal mode (Boulter & Buckley, 2000), as it defines or accounts for how a part of the world functions. In order to identify children's explanations about state changes in the transcripts, we draw from McNeill's (2011) definition of explanation as an account of how and why natural phenomena take place. In interaction of data with literature about complexity of explanations (Kuhn & Pearsall, 2009; Perkins & Grotzer, 2005) a rubric of three levels was developed, according to which elements of an explanation were included in children's talk (Table 6.4). Turns of speech were coded according to these three levels: claims about *components (only)* (level 1), or *components and processes* (level 2) and claims involving *explanations* (level 3). It was not neccessary to establish an additional level involving the identification of processes but not of the components involved, because it did not correspond to our data. It should be noted that a claim could comprise several turns of speech. Repetitions, which are frequent in ECE, were not counted, unless they took place in a different episode.

We consider the two lower coding levels as pre-explanation claims. In level 1, *claims about components (only),* we place statements identifying elements that are relevant for the phenomena. In level 2, *claims about components and processes*, there is an identification of both the components and the processes they go through. In level 3, *claims involving explanations,* we place statements connecting components and/or processes in an explanation that meets at least one the following criteria:

a) A causal relationship is expressed
b) A given explanation is applied to a different context
c) The statement accounts for how a process takes place
d) The statement relates phenomena and model

Table 6.4. Coding categories for children's explanations

Level	Definition	Example from ECE3-L
1	Claims about components: Identifying components relevant for the phenomena	Clouds are made out of water[1]
2	Claims about components and processes: Identifying components and processes relevant for the phenomena	[*The floor*] is going to dry[2]
3	Claims involving explanations:	
	- Identifying a causal relationship	[*I know the water is warm*] because there is smoke[3]
	- Applying an explanation to a different context	[*In the bags there are no drops*] because they are not closed[4]
	- Accounting for how a process takes place	With the little drops the heat takes them to the mirror[5]
	- Relating phenomena and model	[*In solid state the drops are*] like this, very very close together[6]

Original language:
[1] Las nubes están hechas de agua
[2] [*El suelo*] se va secar
[3] [*Sé que el agua está caliente*] porque hay humo
[4] [*En las bolsas no hay gotas*] porque no están cerradas
[5] Con las gotitas el calor las lleva hasta el espejo
[6] [*En estado sólido las gotas están*] así, muy muy juntas

It should be noted that a claim meeting criterion ‘c’ might not provide an underlying mechanism: as Perkins & Grotzer (2005) acknowledge, mechanisms in causal explanations can vary in a range of complexity, from which the lowest level would involve accounting for a surface mechanism, obvious to experience. In chapter 4 we discussed features and differences of ECE1-L and ECE3-P statements proposing a mechanism for how the radula works.

The number and type of claims in each session were recorded in order to determine evolution along the third year of ECE of children’s ability to build explanations.

Additionally, children’s explanations were examined with a focus on the interaction between everyday knowledge and scientific ideas appropriated through classroom experiences in the formation of the scientific concepts (Fleer & Pramling, 2015).

6.4 RESULTS: CHILDREN’S ABILITY TO BUILD EXPLANATIONS DEPENDS ON HOW THEY EXPERIENCE THE PHENOMENA ADDRESSED

This section answers the research question: *What are the features of ECE3 children’s explanations and how do they evolve along the school year?*

Results of the discourse analysis of the 106 episodes from the 13 sessions (5, 6, 7, 8, 11, 12, 13, 14, 15, 16, 17, 21 and 23) devoted to discussing state changes are discussed next. First, children’s participation in the class discourse is presented; second, we address the types of claims about explanations they produced; third, the evolution of explanations about evaporation and condensation is discussed; and fourth, difficulties in producing explanations about state changes are examined.

6.4.1 Participation in the Classroom Discourse

This section addresses children’s participation in the class discourse. This was registered in order to examine: a) if every child engaged in class talk; and b) if there is a relation between the degree of participation and the ability to build explanations. The 106 episodes examined comprise 5166 turns.

The teacher's interventions sum up 42.5% of the turns. They are devoted to present material and activities, explain and prompt children's discussion. Regarding the children's interventions, we established three levels of participation, according to the percentage of turns of speech of each child in the class talk: high (14.8% - 4.5% %), medium (4.4% - 1.7%) and low (≤1.6%) participation. These levels refer to *only* children's talk; the teacher's turns are not included in the count. The levels were elaborated in interaction with the data. Children's participation is uneven and, although there is no one whose participation is 4.4%, these values are kept to allow for continuity between levels. Results regarding this dimension are summarized in Table 6.5.

Table 6.5. Children's participation in the class talk

Participation	Characterization: % of children's turns	Percentage of children's turns	Children (boys/girls)
High	14.8 % - 4.5 %	41.4%	6 (6/0)
Medium	4.4 % - 1.7 %	10.6%	4 (3/1)
Low	≤1.6 %	48%	13 (4/9)

It has been found that 41.4% of children's turns, denoted as hogh participation, correspond to 6 out of the 23 children in the classroom, all of them boys, denoted as high participation: David (14.8%), Gabriel (6%), Igor (5.5%), Mario (5.4%), Alberto (5.2%) and Romeo (4.5%). The dominance of boys in the class talk has been reported in the literature (e.g. Godinho & Shrimpton, 2002). David's participation is very high. Along the three years of study he was usually in-task and participated frequently in the class talk. Four children have medium participation and their turns sum up 10.6% of children's turns. They are three boys, Alejo (3.6%), Amaro (3.2%), and Sebastian (2.1%); and one girl, Andrea (1.7%). From the in-depth analysis of the discourse that is presented next, it has been found that a lower degree of participation in the class talk does not necessarily mean poorer understandings or lower sophistication of children's interventions. For instance, Andrea did not intervene much in the class talk, however when she did so, she showed to be in-task, because she was able to formulate explanations and hypothesis drawing on her peers' ideas and classroom experiences. The remaining 13 children (4 boys and 9 girls) participated each in ≤1.6 %

of the turns. In this level are also counted those turns in which we were not able to identify who was speaking. These represent 48% of the turns. Within this range of participation there are children as Aitor or Loreto, who did not intervene often in talk about explanations, although they showed mastery in other practices, such as producing scientific representations, as discussed in chapter 5.

6.4.2 Claims about Explanations in Children's Discourse

The turns in which these children referred in their talk to components and processes; or provided explanations regarding water state changes were identified. A total of 489 turns (9.5% of the 5166 turns examined, which include teacher's) were identified and coded according to the rubric presented in Table 6.4. From these 489 children's turns, 145 were coded as Level 1, claims about components, (30%); 244 as Level 2, claims about components and processes (50%); and 100 as Level 3 (20%), claims involving explanations. From the 100 turns coded as Level 3, 51 (10% of the coded turns) correspond to the construction of causal explanations; 23 (5%) to build claims that account for how a phenomenon takes place; 19 (4%) to claims that relate a phenomenon with dimensions represented in the model; and seven (1%) to applying an explanation to a new context. Table 6.6 summarizes these results.

Table 6.6. Claims about explanations in Children's Discourse. N=489

Type of claim (Level)	Number	Percentage
Claims about components (1)	**145**	30%
Claims about processes (2)	**244**	50%
Claims involving explanations (3) From these: - Identifying a causal relationship - Applying an explanation to a different context - Accounting for how a process takes place - Relating phenomena and model	**100** 51 7 23 19	20% 10% 1% 5% 4%

Regarding the evolution of children's explanations along the sessions, Figure 6.1 shows the percentage of turns coded as Level 1, Level 2, and Level 3 in each session. The results are presented as percentages from all the turns in each session, in order to allow for comparison of children's performances between sessions. It should be noted the great variability in the number of turns of speech comprised by each session, that range from 193 to 699 turns.

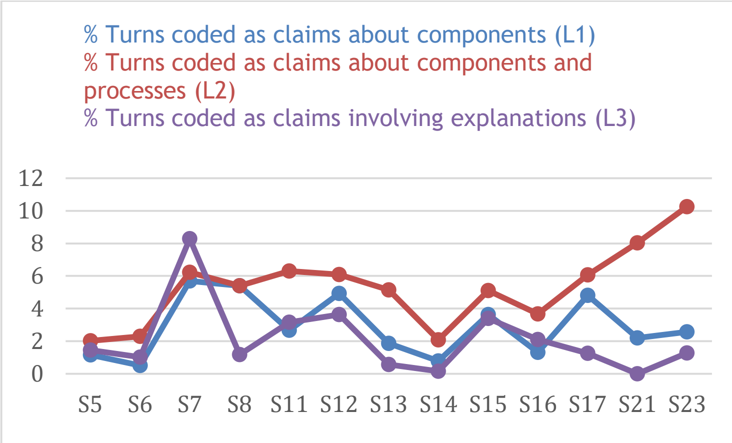


Figure 6.1. Evolution of turns coded as claims about components (L1), claims about components processes (L2) and claims involving explanations (L3) along the sessions

The results represented in Figure 6.1 can be summarized as: first, in all sessions but two, the majority of children's claims are coded as Level 2, that is, children are able to identify components and processes – it should be noted that claims in Level 2 represent 50% of the claims about explanations identified; and second, children were able to build explanations (Level 3) in all the sessions except in session 21. As illustrated by Figure 6.1, children's claims do not follow a clear trend of evolution along the course of the project. That is, there is not an increasing number of claims in Level 3 as the project advances, as it might be expected. This is discussed in the following section. The number of claims in each level varies in a non-linear way along the sessions, which we interpret as that children's ability to build explanations is content dependent: it varies in relation to the phenomena covered in each session and in which ways they are addressed. The two processes covered in-depth along the sessions were *evaporation* and *condensation*. Children's ability to explain them had some differences, as discussed next.

6.4.3 Evolution in Building and Using Explanations about Evaporation and Condensation

This section addresses the features of children's construction and use of explanations about evaporation and condensation. It should be noted that, due to the great differences in participation in the class talk, this discussion focuses only on the 10 children whose participation was high and medium, as for the remaining 13 it was not possible to ascertain a pattern in the evolution of their oral explanations.

The overall results regarding construction and use of explanations can be summarized as follows:

- First, it was easier for children to produce explanations about evaporation than about condensation.

- Second, children produced explanations about both phenomena in the three levels.

- Third, children's explanations were based both on their everyday knowledge and on scientific school knowledge addressed in the classroom. With scientific school knowledge, we refer to a special type of scientific knowledge that is discussed and appropriated in the classroom through engagement in the science project.

Table 6.7 summarizes the contents of the episodes devoted to study water state changes, which are discussed next in relation to children's explanations.

Table 6.7. Contents of the selected episodes

Session	Content: topic/action
5	- Experiment 1 'Evaporation' - Explaining why the floor dries
6	- Checking bags from experiment 1 'Evaporation' - Setting experiment 2 'Boiling' - Explaining condensation in daily life - Applying explanations from experiment 2 'Boiling' to experiment 1 'Evaporation' - Discussing what is frost and why there is frost
7	- Making a "cloud" with breath on a plastic - Discussing rain formation - Discussing condensation and evaporation of water in breath - Reviewing explanations for experiment 1 'Evaporation'
8	- Experiment 2 'Boiling' - Discussing states of water

	- Discussing evaporation - ‘Boiling game’ - Drawing experiment 2‘Boiling’
11	- Experiment 3 ‘Making a cloud’ (3.1 and 3.2) - Discussing rain formation
12	- Discussing clouds and rain formation - Experiment 4 ‘Making rain’ inside the ‘Ecosystem’ (4.1) in large and small group
13	- Experiment 3 ‘Making a cloud’ (3.1 and 3.2) - Discussing that there is smell and dust in the air of the classroom
14	- Discussing the representation of the measures of experiment 1 ‘Evaporation’ - Drawing experiment 1‘Evaporation’
15	- Watching a video about the water cycle - The ‘Three states game’ - Discussing condensation
16	- The ‘Three states game’ - Discussing evaporation and condensation - Drawing the three states of water
17	- Experiment 3 ‘Making a cloud’ (3.2) in large and small group
21	- Experiment 4 ‘Making rain’ outside the ‘Ecosystem’ (4.2)
23	- Experiment 4 ‘Making rain’ outside the ‘Ecosystem’ (4.2)

The evolution of children’s explanations about evaporation and condensation of water, based on everyday and school scientific knowledge is illustrated by Figure 6.2 and is subsequently discussed. On the left and right side of the figure we represent, respectively, children’s explanations about evaporation and condensation that are representative of their evolution along the project. The two columns on the center show both types of knowledge mobilized by children to build their explanations: everyday and scientific school knowledge. In the figure, we indicate the sessions in which the explanations were first produced or the knowledge was first mobilized. It should be noted that not all the sessions are included in this figure, but only those in which key changes in children’s explanations took place.

Explanations about evaporation evolved mainly during sessions 5, 6 and 7, when children carried out experiments ‘Evaporation’ and ‘Boiling’ (see Table 6.7), as summarized in Figure 6.2. During these three sessions, they were able to recognise the process as a state change from liquid to gas, established a causal relationship with temperature; they explained that heat made the little drops to abandon the bulk of water and applied their explanations to other contexts. In session 8 children learnt the terms “liquid” and “gas” and applied them to explain this process. All but one found difficulties to accept that evaporated water could end up in the air. These difficulties were partly overcome after the teacher made use, in session 13, of two models in order to help them to visualize that there can be particles in the air. In the remaining sessions, they were able to apply their explanations about evaporation to the experiments ‘Making a cloud’ and ‘Maing rain’ and to evaporation phenomena in their daily life.

Regarding condensation, explanations evolved mainly during sessions 5, 6 and 7. Children identified it as “mist” and related its appearance to heat and cold. Nevertheless, they did not referred to the process as a state change from gas to liquid, but to drops that get “stuck”. They were not able to recognize condensation in different contexts in the following sessions. For instance, they failed in identifying and explaining condensation of water drops in the air in experiments ‘Making a cloud’ and ‘Making rain’, although they recognized the “mist” on the jar’s walls from experiment 3.

Next, these key sessions are discussed in-depth.

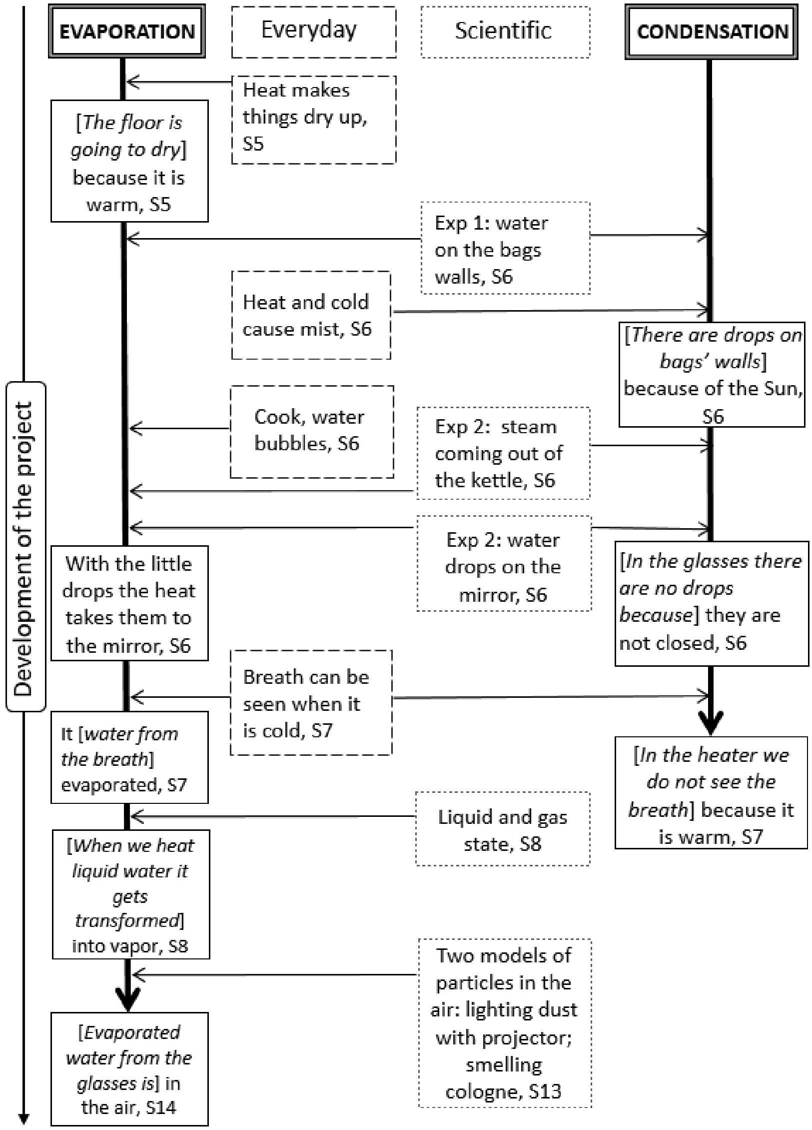


Figure 6.2. Evolution of children's explanations about evaporation and condensation along the sessions (S-n). Legend: Exp1: experiment 1, 'Evaporation'; Exp2: experiment 2, 'Boiling'

Session 5: The lowest number of claims involving explanations has been found in this session. This is understandable because, on the one hand, children started to study state changes systematically in this session; and, on the other hand, in this the session they were not provided with opportunities for observing neither evaporation nor condensation. Even though, four claims about components (Level 1) and five about components and processes (Level 2) related to state changes were identified. Children also produced five explanations (Level 3), related to their everyday experiences about drying.

In this session, children were coming back to the class from the courtyard where they had been observing clouds. The teacher asked them about what were clouds made of. Children answered "Water". Then, she introduced the experiment 'Evaporation'. She told them that they were setting it out in order to learn how water could get to the clouds. This introduction had an effect in children's design proposals, as illustrated by the following excerpt:

Teacher: And we are going to think if, it is, eh… this water here… how could this water get to the clouds. We think.
Alberto: [...] we leave it there for some days…
Several children talk at once.
Teacher: The coldest it [*weather*] is… clouds are made?
David: No! The more water, the more water!
A girl: We wait some days…
Teacher: We wait some days… and what does it happen?
Several: That it [*water*] is converted into clouds!

Original language:
Mestra: Y vamos a pensar se é, eh... esta auga aquí... como poderá chegar esta auga ás nubes. Pensamos.
Alberto: (...) lo dejamos ahí unos días...
Varios nenos falan á vez.
Mestra: Cuanto más frío... ¿se hacen nubes?
David: ¡No! ¡Cuanto más agua, cuanto más agua!
(…)
Unha nena: Esperamos unos días...
Mestra: Esperamos unos días... y que pasa?
Varios nenos: ¡Que se convierte en nubes!

In this excerpt, children acknowledged that water needs to *be converted* to become a cloud (Level 2, processes) and related the greater amount of water to cloud formation (L3, causal relationship). Mario proposed *how* the process could take place:

> Mario: [*First*] A little one [*cloud is going to get formed*], then a medium sized one…
>
> Original language:
> Mario: [*Se va a formar primero*] Una pequeña, luego una mediana...

As part of her commitment to science practices, the teacher's approach to experimentation includes recording measures. David related the height of water they poured in the glasses of the experiment (3 cm) to the size of the cloud that he expected to obtain:

> David: Then that clooooud… I think is going to measure… three centimeters, for it to be in the sky.
>
> Original language:
> David: Pues esa nubeee... creo que va a medir... tres centímetros, para que... esté en el cielo.

By the end of the session, the teacher pointed out to the water that fell on the floor while they were setting the experiment:

> Teacher: So, what happens with that water? When is it washed? Is it going to be here in a while?
> Several: It is going to dry.
> Teacher: And how is it going to dry?
> Mario: Because it is warm.
>
> Original language:
> Mestra: E entón que pasa con esa auga? Cando se frega? Dentro dun rato vai seguir aquí?
> Varios: Se va a secar.
> Mestra: E como se vai secar?
> Mario: Por el calor que hace.

Mario provided a causal explanation about the role of heat in the process, based on his everyday experiences about drying. He did not explain, though, how drying takes place, or that the process involves a state change.

Session 6: the processes discussed were condensation and evaporation. Four claims involving explanations were identified. A clear improvement in children's explanations about evaporation took place in this session after they carried out the experiment 'Boiling'. They became able to account for *why* and *how* the process takes place; and to *apply* their explanations to the experiment 'Evaporation'. Children's claims about the condensation process were of lower complexity than those about evaporation. They referred to the existence of the process and related it to the variable temperature, based on their everyday knowledge.

At the beginning of the session, children were checking the bags from the experiment 'Evaporation' and observed the water drops on the inner walls of the bags:

Alberto: Water drops.
Teacher: Water drops?
Alberto: In [*inside*] the bag.
Teacher: […] Where are they?
Alberto: Up in the thing.
Teacher: Oh! And how can it be that the drops are up there?
Alberto: [*Because*] of the heat?
Teacher: Because of the heat? Heat from the heater? But… where is the bag stuck?
Several children: Outside!
David. Ah, it is because of the Sun.
Teacher: Is the bag facing the Sun?
Igor: No, because it is hot.
The teacher asks Gabriel to have a look to the bag.
Gabriel: It is a bit misted.
Teacher: What is that?
Gabriel: It is because of the cold.
Teacher: Because of the cold, right? But, what does it mean that it is misted?
Gabriel: That it is wet.

Original language:
Alberto: Gotas de agua.
Mestra: Gotas de agua?
Alberto: En la bolsa.
Mestra: […] Donde están?
Alberto: Arriba del *coso*.
Mestra: Anda! Y como puede ser que estén las gotas arriba?
Alberto: Del calor?
Mestra: Como del calor? Del calor del radiador? Pero onde está pegada a bolsa?
Varios: Fuera!
David: Ah, fue por el sol!
Mestra: Lle está dando o sol a bolsa?
Igor: No, porque hace calor.
A mestra manda a mirar a Gabriel.
Gabriel: Está un poco empañada.
Mestra: E que é eso.
Gabriel: Es por el frío.
Mestra: Por el frío, si? Pero que significa eso de que está empañada?
Gabriel: Es que está mojada.

Following the recognition of components ("water drops") and processes ("it is misted"), the children proposed causal explanations. Like Mario in the previous session, they mobilized their everyday knowledge about temperature and relate both "the heat" and "the cold" to the presence of water drops. That is, they connected the process to its causes. They did not mention a source for the water drops. David proposed an alternative explanation related to the experimental procedures:

David: I think that that [*the presence of drops*] is because when we pour the water, I think that surely, some of it went to the sides and the drops got stuck.

Original language:
David: Yo creo que esa es porque cuando le echamos la agua seguramente creo que se fue para los lados y se pegaron las gotas.

Then, the teacher proceeded to introduce the experiment 'Boiling'. While setting the materials, she prompted the children to explain what happened when their parents cooked pasta at home and they answered that "[*When the water is heated, it*] makes bubbles". This claim was coded as an explanation, as it relates the production of bubbles to heat. Then, children observed the boiling water in the kettle. Again, they applied their everyday idea about the role of heat to explain what was happening: "[*I know the water is warm because*] there is smoke". Children observed the empty kettle. When they touched the mirror placed above, they realized there was water and identified the 'smoke' as water:

Teacher: What there is there on the mirror?
Several: Water!
Teacher: When I placed the mirror over the kettle, how was it?
Several: With water.
Teacher: When I put the mirror over the kettle, was it with water?
Several: No.
Miguel: Maybe the water is the smoke.
Teacher: Look, what happened here inside [*the kettle*]. Where is the water that was inside here?
Several: There [*pointing to the mirror*].
Teacher: And how did the water get here?
Several children speaking all at once.
Alberto: The heat! Heat!
David: With the little drops the heat takes them to the mirror.

Original language:
Mestra: Que hai no espello?
Varios: Auga!
Mestra: Cando eu puxen o espello encima do quentador como estaba?
Varios: Con agua.
Mestra: Cando eu puxen o espello encima do quentador estaba con auga?
Varios: Non.
Miguel: A lo mejor es el fume la auga.
Mestra: Mirade o que pasou aquí dentro? Donde vai a auga que estaba aquí dentro?

Varios: Aí [*sinalando o espello*]
Mestra: Y como llegó el agua hasta aquí?
Falan moitos á vez.
Alberto: El calor! Calor!
David: Con las gotitas de agua el calor las lleva hasta el espejo.

In this excerpt, children assumed that liquid water can be transformed into "smoke" when heated. It should be noted that, by this session, they did not know the terms *solid, liquid* and *gas* applied to water. Children use the following pieces of evidence generated through experimentation to build their explanations: 1) there is smoke going out from the kettle, 2) at the end of the experiment there is no more water in the kettle, and 3) there is water on the mirror. In the last turn, David even provides a mechanism that accounts for the way water was moved, in little drops.

After this experience, children assumed that water drops were able to move from the bulk of liquid water. The teacher told them the scientific term of the process: "evaporation". They came back to the bags from the experiment 'Evaporation', and reformulated their explanations:

Teacher: Now, do you know what are these water drops that are in the bags?
David: It is evaporating.
Teacher: It is evaporating… what?
David: The little drops!
Miguel: … Water!
Teacher: Look, look, listen to Miguel.
Miguel: The sun dry them, and then…
Teacher: David, Miguel is speaking! Wait a moment.
Miguel: The Sun heats them and then… it evaporated… and it becomes a cloud.

Original language:
Mestra: Agora xa sabedes que son estas pingas de auga que hai nas bolsas?
David: Se está evaporando.
Mestra: Se está evaporando... o que?

David. ¡Las gotitas!
Miguel: … auga!
Mestra: Mira, mira, escoitade a Miguel.
Miguel: O sol o secan, y luego...
Mestra: David, ¡está hablando Miguel! Espera un momento.
Miguel: El sol las calienta y después... se evapora...y se hace nube.

It should be noted that, although in this excerpt children accounted for how evaporation takes place and its causes, they did not discuss condensation. Miguel pointed to the clouds as the final destiny of the water from the experiment, which is related to how the experiment was introduced. Afterwards, children applied the explanations generated in the course of this session to a new context, in order to account for the differences between glasses and bags: "[*In the glasses there are no drops because*] they are not closed".

Session 7: the highest percentage of turns coded as explanations was found in this session (see Figure 6.1). This is related to the high number of claims about evaporation and to children's ability to apply them to their everyday experiences that were discussed in the course of the session. Regarding condesnation, children were able to identify that it was observable at low temperatures. In this session, they also produced claims about components and processes related to both condensation and evaporation.

This session started in the school courtyard, where children were making a "cloud" with their breath on the plastic of the 'Cloudscope'. It should be noted that being able to see their own breath in winter is a familiar experience for these children:

Teacher: What were we doing now with the 'Cloudscope'?
David: Blow our breath on the 'Cloudscope'. That got with water!
Mario: It evaporated! The water from the breath!
Teacher: Which water evaporated? If I am doing like this [*she blows her breath*], is there water?
Mario: No, only when you are outside.
Teacher: Only when you are outside?
Boy: When it is cold…

Original language:

Teacher: Que fixemos agora co ‘Nuboscopio’?
David: Echar nuestro aliento en el ‘Nuboscopio’. Que se puso con agua!
Mario: Se evaporó! El agua del aliento.
Mestra. Que agua se evaporó? Si yo hago así, hay agua?
Mario: No, solo cuando estás fuera.
Mestra: Solo cuando estás fuera?
Neno: Cuando está frío…

Everyday knowledge (“only when you are outside”) and scientific knowledge from the classroom (“it evaporated”) interact in children’s explanations in this excerpt. Then, the teacher directed the conversation towards the phenomena of condensation and evaporation, observed in the experiment ‘Boiling’.

Alberto: That the little drops evaporated and went up to the mirror.
Teacher: That the little drops evaporated and went up to the mirror. And what happened in the mirror? They got…
Several: Stuck!

Original language:
Alberto: Que las gotitas se evaporaron y se subieron al espejo.
Mestra: Que las gotitas se evaporaron y se subieron al espejo. Y en el espejo que pasó? Se quedaron…
Varios: Pegadas!

It should be noted that children’s use of “stuck” does not imply that they consider that water undergoes a transformation. The teacher then made explicit the role of temperature in this process. As a result, eventually, Alberto applied the explanation to a new context:

Teacher: But, how is the air we blew from our mouth?
Child: Warm.
Teacher: And the ‘Cloudscope’?
David: Warm. Cold.
Teacher: How is the ‘Cloudscope’?
Several: Cold.
Teacher: How is the mirror?
Several: Cold.

The teacher explains that, when water from the breath encounters something cold, it gets cold and little drops get formed, because of the different temperature. She says they can do that on other surfaces:

Alberto: On the window!

Teacher: And why it does not work here? [*blows her breath towards the heater*].

Alberto: Because it is warm.

Original language:

Mestra: Pero como es el aire que echamos de la boca?

Non identificado: Caliente.

Mestra: E o 'Nuboscopio'?

David: Quente. Frío.

Mestra: Como está o 'Nuboscopio'?

Varios: Frío.

Mestra: Como está o espello?

Varios: Frío.

A mestra explícalles que cando a auga do bafo encontra algo frío, enfríase fórmanse gotiñas, pola diferencia de temperatura. Dilles que o poden facer noutras superficies.

Alberto: En la ventana!

Mestra: E por que aquí non me sale? [*bota o bafo no radiador da aula*].

Alberto: Porque está caliente!

The teacher kept on questioning children about the role of temperature so that they made explicit which were the sources of heat:

Teacher: So, what happened with the water outside [*in the bag that was left outside the classroom's window*].

Mario: That one received cold and the other one received heat.

Teacher: But it happened the same.

Child: Because at night it went down [*the temperature*].

Teacher: Igor?

Igor: Because I saw in TV that the more the heat or water then if it is hot the water gets warm.

Teacher: Is it hot outside?

Several: No.

Gabriel: Eh! It was because of the Sun!

Ariadna: It was sunny some days!

Teacher: And what did it happen with the Sun?
Several: It heated it!

Original language:
Mestra: Entón que pasou coa auga de fora?
Mario: Que una le dio el frío y la otra le dio el calor.
Mestra: Pero pasó lo mismo.
Non identificado: Porque de noche bajó.
Mestra: Igor?
Igor: Porque vi en la tele que cuanto más calor o agua pues si hay calor se va calentando el agua.
Mestra: Ahí fuera hace calor?
Varios: No.
Gabriel: Eh! Fue por el sol!
Ariadna: Unos días hizo sol!
Mestra: E que pasou co sol?
Varios: Le dio calor!

By the end of the session, children discussed condensation and evaporation in their everyday experiences:

Igor: Because when I took a bath my mum said that now she opens the window so that the evaporated escapes and I painted on the window.
Mario: On the shower panel too.
Sebastian: And on the light [*sunbeam*]. Because my mother told me, I asked her and it was evaporating.

Original language:
Igor: Porque cuando yo me bañé mi mamá dijo que ahora abre la ventana para que escape el evaporado y pinté en la ventana.
Mario: En las mamparas también.
Sebastian: Y en la luz. Porque me lo dijo mi madre, se lo pregunté y se estaba evaporando.

Then, the teacher pointed to the bags from the experiment 'Evaporation' and asked children how is that water got to the bags' walls:

Igor: Because inside the bags if you put it inside a house, but if it is very hot, of course, it happens the same.

Original language:
Igor: Porque dentro de las bolsas si lo pones dentro de una casa, pero si hace mucho calor, claro, pasa o mismo.

In the last turn, Igor pointed to an important aspect, the universality of physical processes in different contexts: “if it is very hot, of course, it happens the same”.

Session 8: the frequency of explanations decreased because the concept of the three states of water, which was new for children, was discussed for the first time. Children’s explanations in this session regarded the evaporation process and the relation between the experiment ‘Boiling’ and the ‘Boiling game’ (see Table 6.2). When children enacted the ‘Boiling game’, they were able to explain that their increasing speed represented the change from liquid to gas observed in the experiment. While representing the experiment with a drawing, they produced mainly claims about components and processes.

At the beginning of session 8, the experiment ‘Boiling’ was repeated. The children did not devote so much time as in previous sessions to discuss it. They pointed to the processes they were observing: evaporation of water and water drops that get to the mirror. But they did not produce explanations, as they had already discussed in-depth this experiment in previous sessions. The teacher introduced then the topic and scientific term for the three states of water:

Teacher: What is water, what is? What is coca-cola? What is…?
Boy: They are drinks!
Alberto: Liquid.
Teacher: Very well. It is water… liquid!! All right, guys? Its state is liquid. When it is in the freezer… How is it?
Boy: Liquid.
Teacher: In the freezer?
Several: Cold, liquid…
Girl: Hard!

Teacher: It is hard, it is not liquid. It is so-lid. The water when it is in the freezer and gets frozen is solid. When we get it from the tap or it is in a bottle, or it is like this, room temperature… it is… how?

Girl: Solid.

Alberto: Liquid.

Teacher: Liquid. And when the water gets heated… when we heat it… what does that water become?

Several: Vapoooooooor!

Teacher: Water vapor. […] Very well, guys. These are the three possible ways in which water can be. Water can be in state…

Gabriel: United!

Teacher: United, yes [*laughing*]. United States… In liquid state, that is this one [*she raises a bottle of water*].

Boy: In hard state!

Teacher: In hard state, that is the solid state. Very well.

Alberto: And in warm state.

Teacher: And in state…? Vapor, that it is called “gas”. All right? These are difficult words.

Original language:

Mestra. ¿Qué es el agua, qué es? ¿Qué es la coca-cola? ¿Qué es el...?

Un neno. ¡Son bebidas!

Alberto. Líquida.

[…]

Mestra. Muy bien. Es agua... ¡¡líquida!! ¡Está líquida! ¿Vale, chicos? Su estado es líquido. Cuando está en el congelador... ¿cómo está?

Un neno. Líquida.

Mestra. ¿En el congelador?

Varios nenos. Fría, líquida...

Unha nena. ¡Dura!

Mestra. Está dura, no está líquida. Está só-li-da. El agua cuando está en el congelador y se congela, está sólida. Cuando la sacamos del grifo o está en una botella, o está así a temperatura normal... está... ¿cómo?

Unha nena. Sólida.

Alberto. Líquida.

Mestra. Líquida. Y, y... cuando el agua se calienta... cando a quentamos... co... en qué se convirte esa auga?

Varios. En vapooor.

Mestra. En vapor de auga […]. Moi ben, chicos!! Esas son as tres formas posibles nas que pode estar a auga. A auga pode estar en estado...

Gabriel: Unidos.

Mestra: Unido, si [*Ri*]. En Estados Unidos... En estado líquido, que es esta.

Un neno: En estado duro!

Mestra: En estado duro, que es el estado sólido. Muy bien.

Alberto: Y en estado... caliente.

Mestra: Y en estado...? Vapor, que se dice estado "ga-se-o-so". Vale? Son palabras difíciles.

As seen in the previous excerpt, children used their own words to identify the three states. The teacher supported this use, whilst at the same time, introducing the scientific vocabulary: "In hard state, that is the solid state. Very well". It should be noted that since session 6 children assumed that evaporation involved a change in the water, although they did not learn the scientific terms "liquid" and "gas" until this session.

The teacher tried to get the children to use the new vocabulary to explain the experiment 'Boiling':

Teacher: What did we pour here [*in the kettle*]?

Children: Water.

Teacher: Water… water, what?

Children: Liquid.

Teacher: Liquid. When we give heat to liquid water… Javier!!! Sit down. What does it happen to it?

Andrea: It evaporates.

Teacher: No. When we heat liquid water… What does it happen to that liquid water?

Mario: It gets frozen.

Boy: It gets transformed into…

Teacher: It gets frozen??? This is when we give it cold, Mario […] You are not being attentive!

Alberto: It gets transformed into nothing.

Teacher: It gets transformed into what?

Alberto. Into nothing.

Teacher. Into nothing, not. Into what?

Boy: Into water.

Andrea: Into vapor.

Original language:
Mestra: O que botamos aquí era que?
Os nenos: Agua.
Mestra: Agua... auga, que?
Os nenos: Líquida.
Mestra: Líquida. Cando lle damos calor á auga líquida... Javier!!! Siéntate. Que lle pasa?
Andrea: Se evapora.
Mestra: No. Cando lle damos calor á auga líquida... que lle pasa a esa auga líquida?
Mario: Se congela.
Neno: Se convierte en...
Mestra: ¿¿Se congela?? Eso é cando lle damos frío, Mario. (...) Non estades atentos!
Alberto: Pues se convierte en nada.
Mestra: ¿En qué se convierte?
Alberto: En nada.
Mestra: En nada no. En que?
Un neno: En agua!
Andrea: En vapor.

Children were able to apply the scientific terms "liquid water" and "evaporation" to the experiment, even though the teacher rejected this last one because she was looking for a different one: "vapor". This is one of the excerpts in which Andrea, the girl with medium participation, contributed to classroom talk showing to be in-task.

Next, Mario was "doing the lesson". He answered: "frozen", a term that he knew is related, somehow, to what the teacher was looking for. Alberto tried to solve the question by saying that the water becomes "nothing". This claim seems to be related to the fact that water in the air is not visible. Similarly, children provided explanations for the evaporation of water from the kettle but struggled to account for the evaporation of water on the mirror. This different ability seems to be related to the fact that in the experiment 'Boiling' the evaporated water from the kettle collides with the mirror and condenses on it, which is a visible process; whereas from the mirror it evaporates and becomes part of the air in the class, where the water drops are not visible. This fact made more demanding for children to account for the process:

Teacher: Where is the water that was in the mirror.
Javier: It dried.
Teacher: It dried, yes, very well... but… where is it?
Boy: It went to the clouds.
[*A lot of noise*]
Teacher: It went to the clouds? Through where?
Boy: Through there…
Boy: Through a hole…
Igor: It is in the air.
Teacher: Right. Then… Sure… It is in the air.

Original language:
Mestra: ¿Dónde está el agua que estaba en el espejo?
Javier: Se secó.
Mestra: Se secó, sí, muy bien... pero... ¿dónde está?
Un neno: Se fue a las nubes.
Moito barullo.
Mestra: ¿¿Se marchó a las nubes?? ¿Por dónde?
Non id: Por allá...
Un neno: Por una burato.
Igor: Está no aire.
Mestra. Vale. Entón... Claro... está no aire.

The idea that water becomes a cloud when it evaporates unless it "sticks" on a surface, promoted by the teacher when she introduced the experiment 'Evaporation' in session 5, was still recalled by children. Only one child, Igor, stated that water was in the air.

Session 13: children eventually accepted the notion of "water in the air" after the teacher made use of two models to help them to visualize particles in the air. She did so in order to facilitate their understandings about condensation in the air in experiments 'Making a cloud' and 'Making rain', carried out in sessions 12 and 13 (see Table 6.7). First, she poured perfume on one corner of the class and prompted children to explain how the smell could be spread all over:

Teacher: How can cologne get here?
Igor: Because the air…
Teacher: Because the air…

Igor: It pushed it.
Teacher: It pushed it. Where is the air?
Sebastian: There, there [*pointing to the air*].

Original language:
Mestra: ¿Cómo puede llegar la colonia ahí?
Igor: Porque el aire...
Mestra: Porque el aire...?
Igor: La empujó.
Mestra: Lo empujó. ¿Dónde está el aire?
Sebastian: Ahí, ahí.

Second, she switched on the class' projector so that the children were able to see the dust in the air. She prompted them to "imagine" that water in the air was like the dust. She told them that it was there, but that they could not see it.

Session 14: David and another two children applied then the notion of water in the air to the glasses from the experiment 'Evaporation'. It should be noted that David used indistinctly the terms "air" and "wind":

Teacher: Then… the water that evaporated from the glass… the water that evaporated from this glass… that it is there… that water…
David: It is in the wind.
Teacher: Noo.
Boy: In the air.
Teacher: It is in the air… where from?
David and another boy: From here.
Teacher: From this class!
David: What happens is that everything… Outside, here, everywhere… there is air.

Original language:
Mestra: Entón... A auga que se evapora do vaso... A auga que se evapora dese vaso... que está ahí... esa auga...
David: Está en el viento.
Mestra: Noo.
Un neno: En el aire.
Mestra: Está en el aire... ¿de dónde?
David e outro neno: De aquí.

Mestra: ¡De esta clase!
David: Es que todo... Fuera, aquí, en todos lados... hay aire.

6.4.4 Children's Difficulties in Explaining State Changes

In the course of the remaining sessions we have not identified any new dimensions in children's explanations about state changes. Their performances and difficulties are discussed next. During these sessions, children carried out the experiments 3, 'Making a cloud', and 4, 'Making rain'; discussed rain and cloud formation; and enacted the models of 'The three states' and 'The water cycle' (see Table 6.6).

Regarding the interpretation of the models enacted, 'The three states' and 'The water cycle', children were able to relate the dimensions of the model to the phenomena, like they did in session 8 when they enacted the experiment 'Boiling'. For instance, in session 15 they explained the representation of the three states of water:

Teacher: How is water in solid state? What is the water in solid state?
Romeo: Then…
Teacher: Romeo is thinking, very well, Romeo.
Mario: Ice.
Teacher: It is ice. Water in solid state is ice. How do you think that the little drops are, there, in solid state?
Andrea: Cold.
Teacher: [*answering back to a child*] Together. How close together?
Child: Like this, very close together.
Teacher: Very close together, very close together, very close together, very close together? Held together or on their own?
Several: Held together.
[…]
Teacher: How are the drops in gas state?
Romeo: Eeeeh. Separated.
Gabriel: Running!

Original language:
Mestra: Como está a auga en estado sólido? Que é a auga en estado sólido?
Romeo: Pueees...
Mestra: Romeo, está pensando, muy bien, Romeo.

Mario: Hielo.

Mestra: É xeo. A auga en estado sólido é xeo. Como pensades vós que están as pinguiñas de auga, aí, en estado sólido?

Andrea: Frías.

Mestra (como respondendo a alguén): Juntas. ¿Cómo de juntas?

Un neno ou unha nena: Así, muy juntas.

Mestra: ¿Muy juntas, muy juntas, muy juntas, muy juntas? ¿Agarradas o sueltas?

Varios nenos: Agarradas.

[…]

Mestra: Como están as pingas, en estado gaseoso?

Romeo: Eeeh.. separadas.

Gabriel: ¡Corriendo!

Even though children were able to relate their movements to what they were representing, it does not seem to help them to explain the state change from gas to liquid, as discussed next in relation to how they apply their explanations to cloud and rain formation and to the interpretation of experiments 3 and 4.

Children did not use the idea of condensation in their explanations about rain and cloud formation. In both cases they did refer to the process of evaporation that caused water to go to the sky. In sessions 11, 12, 15, 16 and 21, children explained that rain fell because water "drops" got together and there was too much weight of water, but did not point to condensation. The term *condensation* was introduced in session 15 with a video about the water cycle. Children struggled to use it and to apply it to cloud and rain formation:

Teacher: How can the [*clouds*] stay there? There, in… in the sky.

Gabriel: They can fall.

Teacher: When they fall?

Gabriel: Through the air, and…

Gabriel and Andrea speak at once.

Teacher: Louder, Andrea.

Andrea: That the little drops are so, so, so little… that the air can hold them.

Teacher: Very well! The air holds them and when they are together… we see a cloud, right? Right? And when does it start, then…

to precipitate, that? When does it start? For instance, when we made rain… in the [*model*] ‘Ecosystem’, when did it start raining? When the water did first got stuck?

Gabriel and other children: Aboooove!!

Teacher: On the glasses. How is that called… when water gets stuck on the glasses, how is that called? […] When water gets stuck on the glasses, eh, when it gets stuck on the glasses, when it is there… on the clouds… there… close to start raining… it is said that it “con-den-ses” Let’s see how you say it.

Children, in group: Condenses.

Teacher: Condensation.

Children: Condensation.

Teacher: Right, then. First it evaporates… then, when it is… when it is evaporated… it has to condense… and little by little, little drops get back…

David: Together.

Teacher: Get together! And then what happens?

Several: That it rains.

Teacher: That it rain. Right? That is very easy to do, isn’t it, with our body? Yes? Do we do it? Then? Right?

Several: Yes.

Teacher: Why had the little drops to get together?

Gabriel: To be friends.

David: So that… for the river… for raining… for it to rain…

Teacher: And how does it rain, David?

David: Like this, together.

Teacher: Sure. It gets together. What does it need to happen for it to rain?

David: They need to be very close together, the drops.

Original language:

Mestra: Como se poden manter aí? Aí, no... no ceo.

Gabriel: Se pueden caer.

Mestra: Cando se caen?

Gabriel: Por el aire, y...

Gabriel e Andrea falan á vez.

Mestra: Más alto, Andrea.

Andrea: Que las gotitas son tan, tan, tan pequeñitas... que las sostiene el aire.

Mestra: ¡Muy bien! Las sostiene el aire y cuando están juntas... vemos una nube, ¿verdad? ¿Verdad? E cando empeza, entón... a precipitar eso? Cando empeza? Por exemplo, cando fixemos a chuvia... no ecosistem... cando empezou a precipitar? Donde se pegou primeiro a auga?

Gabriel e outros: Arriiiibaa.

Mestra: Nos cristales. Como se chama eso... de cando se pega auga nos cristales, como se chama? […] Cando a auga... se pega no cristales, eh, cando se pega nos cristales, cando está aí... nas nubes... aí a puntito de chover... se di que se... "con-den-sa". A ver como o dicides.

Os nenos, en grupo: Condensa.

Mestra: Condensación.

Os nenos: Condensación.

Mestra: Vale, entón. Primeiro se evapora... despois, cando se está... cando está evaporada... se ten que condensar... y pouco a pouco, as pinguiñas se volven a...

David: Xuntar.

Mestra: Xuntar! Y entón que pasa?

Varios nenos: Que llueve.

Mestra: Que chove. Vale? Eso é facilísimo de facer, no, co noso corpo? Si? Facémolo, entón?

Varios nenos: Si.

Mestra: Por que se tiñan que unir, as pinguiñas?

Gabriel: Para que sean amigas.

David: Para que... para el río... para llover... para que llueva...

Mestra: Y... como chove, David?

David: Así, juntas.

Mestra: Claro. Se junta. Que ten que pasar para que chova?

David: Tienen que estar muy juntas las gotas.

It should be noted that children explained the processes of rain and cloud formation according to a change in the distance between water drops. These explanations are consistent with the water cycle model they enacted with their bodies. In this model, children enacted a river by going together in a line. Then, they "evaporated" by leaving the line and running all around the classroom. Afterwards, they "became a cloud" by making groups of two children and, from this position, they "rained": they formed a line again, to represent the river. Children stated that clouds are made of little drops: "That the little drops are so, so, so little… that the air holds them"; and that when these drops get together, it rains: "[*The drops*] have to be very close together". None of the children mentioned state changes, even though they had also enacted the 'Three states game', in which the state change from gas to liquid implied that the "drops" they represented got together. Despite the teacher's continuous efforts, during the session children did not use the word *condensation* and their difficulties to understand the meaning of this term persisted along the project. Children's difficulties seem to be related to understanding that water changes from gas to liquid when it condenses This is illustrated by the following excerpt, from session 16:

> Teacher: What is condensation, Romeo?
> Romeo: It is… when… the windows are full of water vapor.
> Teacher: When the windows are full of water vapor. But, figure it, figure it out, Romeo. When you see that water on the windows… is the water still water vapor?
> *Several children talk at once.*
> Teacher: And when it condenses what does it happen to it, it gets back to… what to?
> Romeo: To the clouds.
> Teacher: No. It goes from water vapor to... what to?
> Boy: Air.
> Another boy: Solid state?
> Alberto: Is it that the water had the vapor?
> David: To… liquid state!
> Teacher: To liquid state! […] When, when… when those windows get like that, misted, how was it called… How is it called, Romeo?
> Romeo: Condensation.
>
> Original language:
> Mestra: Que era a condensación, Romeo?
> Romeo: Pues... cuando... las ventanas están llenas de vapor de agua.
> Mestra: Cuando las ventanas están llenas de vapor de agua. Pero fíxate, fíxate unha cousa, Romeo. Cando ti ves esa auga nas ventanas... a auga segue sendo vapor de agua?
> *Varios nenos falan á vez.*
> Mestra: Y cando se condensa que lle pasa, volve a... que?
> Romeo: A las nubes.
> Mestra: No... Que pasa de vapor de auga... a que?

Un neno: A aire.
Un neno: ¿A estado sólido?
Alberto: ¿Es que la auga tenía el vapor?
David: A... ¡estado líquido!
Mestra: ¡A estado líquido! […] Cando, cando... cando se poñen esas ventanas así empañadas, que se lle chamaba... Como se lle chama, Romeo?
Romeo: Condensación.

The teacher kept on prompting them to discuss it, although only Igor seemed to relate condensation to rainfall:

Teacher: Sure. Well, Romeo. And when a thing is condensed… when water is condensed… water goes from vapor to…?
Romeo: To liquid state.
Teacher: To liquid state. Because of that, because of that… Where does it happen? Aside from the… windows.
Boy: On the windowpanes.
Teacher: Aside from the windowpanes… where does it happen?
According to the teacher's answer it seems that a child says "In the clouds", but it cannot be heard because there is noise.
Teacher: In the clouds!! When does it happen in the clouds?
Igor: When it rains.

Original language:
Mestra: Claro. Ben, Romeo. Y cando unha cousa se condensa... cando se condensa a auga... A auga pasa de vapor a....?
Romeo: A estado líquido.
Mestra: A estado líquido. Por eso, por eso... ¿Dónde pasa eso? Además de... nas ventanas.
Un neno: En los cristales.
Mestra: Ademáis dos cristales... ¿dónde pasa eso?
[*Barullo. Por como contesta a mestra parece que algún neno di "Nas nubes"*]
Mestra: Nas nubes!! Cando pasa eso nas nubes?
Igor: Cando chove.

Next, Romeo said that he did not understand, so the teacher tried to help him by pointing to the bags from the experiment 'Evaporation':

Teacher: These water droplets are left inside, they are left inside. But… suddenly… when José Antonio [*the janitor, pseudonym*] switches off the heater… when José Antonio switches off the heater…what does it happen to water?

Boy: It evaporates.

Teacher: Noooo.

Igor: Thaaat, thaaat, thaat…

Teacher: It cools, the space cools, the air cools … eh, eh… the air cools… and what happens to that vapor drops… what happens?

Igor: They are cooling.

Teacher: They are cooling…

Igor: And… and they become…

Several children speak at once.

Igor: And they become little water drops.

Original language:

Mestra: Esas pinguiñas de auga quedan aí dentro, quedan aí dentro. Pero... de repente... cando José Antonio apaga a calefacción... cando José Antonio apaga a calefacción... que lle pasa á auga?

Neno: Que se evapora.

Mestra: Noon.

Igor: Queee, queee, quee...

Mestra: Se enfría, se enfría el espacio, se enfría el aire... eh, eh... se enfría el aire... y a esas gotiñas de vapor... que lles pasa?

Igor: Se están enfriando.

Mestra: Se están enfriando...

Igor: Y... y se convierten...

Varios nenos falando á vez.

Igor: Y se convierten en gotitas de agua.

We interpret that when Igor said "water drops" he referred to liquid water. This discussion seemed to have prompted Igor's reflection about the role of condensation in cloud formation:

Igor: How.. how… can they be carried… in the wind… the evaporated water… and how can they be falling…

Teacher: Suuure. And what.. what happens, what does get formed when the wind takes with it the evaporated water? […]

Igor: The liquid state!

Original language:

Igor: Como... como... se pueden llevar... en el viento... el agua evaporada... y se pueden ir cayendo...

Mestra: Claaro. Y que... ¿qué le pasa, que se forma cuando el viento se lleva el agua evaporada? […]

Igor: ...el estado líquido!

In this session, both Romeo and David stated that condensation means that water changes from gas to liquid, but they did not seem to appreciate the full implications of this change because they were not able to apply the term consistently. In fact, Romeo eventually said that he did not understand it. Only one child, Igor, seemed to be able to understand and apply the concept of "condensation" to identify a state change from liquid to gas and to understand that cloud formation involved condensation of water drops in the air.

Children experienced difficulties in applying the explanations about condensation to the experiments 'Making a cloud' and 'Making rain' and they did not change their explanations about the phenomena these experiments stood for.

The two reworked versions of experiment 3 'Making a cloud', were carried out in sessions 11, 13 and 17. They involved observing a swirl of water drops caused by placing warm water on the bottom of a jar and ice on the top of it. The reworked version 3.2 involved introducing a burning match in the jar, so that the swirl was easier to observe. Children identified and described the following processes: evaporation of water, ice melting, water drops getting "stuck" on the jar walls and water drops making a swirl. They explained that the drops did not go out because the jar had the lid on and that the drops were "the cloud", as making a cloud was the target of the experiments. They identified evaporation of warm water on the bottom and condensation on the jar's glass. But they were not able to relate the appearance of the swirl to a change from gas to liquid. Their explanations referred to the processes and to the role of the match in favoring the visualization of the swirl of water drops: "And when it [*the jar*] had the match [*inside*] it was more misted that when it did not have it." In session 17, the teacher directed the discussion to get them to focus on the relation between the processes observed and the gradient of temperature:

Teacher: Let's see, Mario.

Mario: There were little drops that wanted to go out from the jar, that made a swirl.

Teacher: Why did that happen?

Romeo: Because there was hot water.

Teacher: Why??

Romeo: Because there were hot water and ice.

[...]

Teacher: We were talking that what happened inside the jar is very, very similar to what happens in the sky when clouds get formed. Right? So… What is needed for cloud formation?

Several: Ice / water / hot water.

[…]

Teacher: Or … or, I say… that would it be also… that the upper part… were more…

Silence.

Teacher: That the upper part of the sky were more…[…]

Several: Cold.

Teacher: Colder than…

Several: Down.

[…]

Teacher: So… what would be then the conclusion of the experiment, guys? What would it be?

Igor: That… that… that the swirl would be the cloud?

Original language:

Mestra: A ver, Mario.

Mario: Pues que había unas gotitas que querían salir del bote, que hacían un remolino.

Mestra: ¿Por qué pasó eso?

Romeo: Porque había agua caliente.

Mestra: ¿¿Por qué??

Romeo: Porque había agua caliente y hielo.

[...]

Mestra: Estábamos falando que o que pasou dentro do bote é moi, moi semellante ao que pasa no ceo cando se forman as nubes. Vale? Entón... que se necesita para que se formen as nubes?

Varios nenos: Xeo / agua / auga quente.

[…]

Mestra: Ou, ou... digo eu... que será tamén... Que a parte de arriba... esté máis... que? […]

Varios nenos: Fría.

Mestra: Máis fría que a parte de...

Os nenos: Abaixo.

[…]

Mestra: Entón... Cal sería a conclusión do experimento, chicos? Cal sería?

Igor: Que... que... que el remolino sería la nube?

It should be noted that, despite teacher's efforts, children struggled to account for the processes involved. The children experienced similar difficulties for the interpretation of experiment 4, 'Making rain' in its two reworked versions, in sessions 12, 21 and 23. In session 12 children carried out the experiment 'Making rain' inside the 'Ecosystem' model (reworked version 4.1). This experiment involved placing ice on the top of the model and observing the condensation of the water drops inside the game it caused by the decrease in temperature. Children identified processes such as the ice melting on the top of the model, which they believed to be the source of the "rain drops". They built explanations about evaporation. None of them mentioned the condensation of water that could be observed inside the model. In sessions 21 and 23, the experiment 'Making rain' outside the 'Ecosystem' model was carried out. It involved heating water on the kettle and placing the lid of the model above it, so that the drops were interrupted on their way up and condensed. Children's talk focused on describing the processes, evaporation and condensation, when they made predictions before carrying out the experiment; and after they carried it out, when they interpreted their observations. They referred to the process as "condensation", "rain" and "drops get stuck"; but did not explain it in terms of the state change from gas to liquid. Andrea explained that the evaporated water, when it got to the upper part of the model: "It cannot stay and it falls". Although the girl did not specify what she meant by "it cannot stay", this explanation seems to be linked to the idea of rain falling because it "weights too much" that children had been expressing since session 11.

As a summary, it can be said that intervention in the class talk is uneven, and that boys intervene more than girls. A high participation in the class talk is not related, though, to the quality of the explanations produced, neither to children's capability to successfully engage in other types of tasks, such as producing scientific representations. The teacher's interventions sum up 42.5% of the turns and she supported children's explanations through prompts and questioning. The examination of the evolution in explanations from the children who intervened in the class talk with higher frequency indicates that they were able to produce claims in the three levels of coplexity: about components, about components and processes and involving explanations. Nevertheless, there is not a clear trend of evolution along the project; it rather depends on the topics addressed. Children's explanations appealed to both everyday and scientific school knowledge. Children were able to understand and explain that evaporation involves a state change from liquid to gas. They explained why and how the process takes place and applied their explanations to new contexts. Accounting for condensation was found to be more challenging for them. They were able to explain that condensation is related to changes in temperature, but they found difficulties for identifying it in different contexts. Children did not acknowledge that condensation implies a state change from gas to liquid; instead, they described the process as drops that get "stuck". This description has to do with their observations in the course of the experiments and with the models they enacted with their bodies. But they failed to apply the notion of state change involved in these models to explain the experiments, and clouds or rain formation.

6.5 DISCUSSION

This section discusses main findings regarding: 1) the evolution of children's explanations about evaporation and condensation; 2) the interaction of scientific and everyday knowledge in explanation construction; and two emergent findings regarding the role of 3) peer scaffolding; and 4) perception with senses. It should be noted that, in this discussion, we refer only to those children whose intervention in the classroom talk was high or medium.

1) *Children's explanations about state changes evolved along the course of the project, although there were differences for evaporation and condensation*. At the beginning, children were able to identify components and phenomena and to express a relationship with temperature. They were not able to explain how the phenomena took place. From session 5, when they started to study systematically state changes, to 13, from which their explanations did not incorporate any new dimension, children became increasingly capable to identify the phenomena in several contexts, their relation to other factors, for instance, time, accounted for how they take place and related them to dimensions represented in a model. They learnt vocabulary about state changes and used it in their explanations. The teacher provided them with opportunities to repeat the experiments several times, and to reflect back about them, so that they could reformulate their claims in the light of new evidence, and apply their explanations to other contexts. The teacher's strategies are addressed in chapter 7.

Nevertheless, evolution in children's explanations along the project was not linear, but depended on the phenomena addressed. As discussed next, the explanations about evaporation evolved differently than those regarding condensation.

Explanations about evaporation evolved mainly during sessions 5, 6, 7, 8, 13 and 14, when children engaged in carrying out experiments about state changes and discussed them in relation to everyday phenomena. When accounting for the phenomenon of evaporation, children:

- Pointed to a causal relationship with the increase of temperature (criterion a).

- Applied their explanations about evaporation to a range of contexts, such as explaining differences between changes observed in an opened and a closed recipient containing water (criterion b).

- Explicitly related their observations of the process to the change from liquid to gas and explained how it takes place, from a macro and microscopic perspective. For instance, they were able to explain that the decrease in the level of water in the glasses was due to evaporation along the weeks, and also described that it took place because with the heat the little drops went to the air (criterion c).

- Enacted and explained molecular models that account for the distance between water "drops" (sic) and for their velocity (criterion d).

Regarding condensation, explanations evolved in sessions 6, 7 and 8, during which they expressed to recognize "mist", related it to the temperature and eventually explained it as drops that got "stuck". Children were able to:

- Relate the process to changes in temperature (criterion a).
- In one occasion, they were able to apply an explanation to a different context: "[*In the bags there are no drops because*] they are not closed" (criterion b).
- Explain how it takes place: drops get "stuck" (criterion c).
- Enact and explain models of condensation according to the distance between water drops and their velocity (criterion d).

Nevertheless, children were not able to apply the notion of condensation to *all* the contexts they encountered. Tytler and Peterson's (2004) carried out a longitudinal study with a group of students since they were 5 years old until they were 9. They report that students' understandings about state changes depend on the context, especially in the case of younger pupils.

Regarding children's difficulties in explaining condensation, our findings are consistent with Tytler's (2000) comparative study between grade 1 (6-7 years old) and grade 6 students (12-13 years old). This author found that children's ability to employ the notion of water exchange with the air to account for the condensation phenomena was lower than for evaporation and boiling, especially in the case of the younger students. He reports that the differences between younger and older children's ability to apply the notion of water chaging in form to the phenomena of condensation were even higher. Similarly, the critical point in our study seems to be that children struggled to identify a state change from gas to liquid. This understanding might have facilitated children's construction of explanations. Rather, they identified and described condensation as drops that get "stuck". They failed in relating the models they enacted, in which the "drops" that get closer together change from gas to liquid, to different contexts. For the process of evaporation, they did recognize that water undergoes a state change. The few times children used the word condensation, they did so without referring to a state change, but to drops "sticking" on a surface. For instance, children explained the condensation processes in the experiments 'Evaporation', 'Boiling' and 'Making rain' outside the 'Ecosystem' model, according to a collision between evaporated water drops that went up and encountered a surface (mirror, bags or lid of the model 'Ecosystem', respectively). Only once, and strongly guided by the teacher, one child, Igor, explicitly indicated that a state change took place.

2) *Classroom and everyday knowledge mediate children's explanations about state changes.* Classroom knowledge was built through class experiences, such as engagement in experimentation and modeling; and everyday knowledge through experiences such as the daily bath. In the construction of their explanations they used evidence from these experiences and they employed both everyday vocabulary and scientific terms learnt in school.

Based on their everyday knowledge, children showed their awareness about the role that temperature plays in processes that are familiar for them, such as:

- drying of a wet floor
- "smoke" produced when heating water
- melting of ice
- blowing their breath in winter and being able to observe condensation

After engagement in experimentation they were able to relate some everyday phenomena to the processes observed and discussed in the classroom. For instance, children related their observations of condensation in the experiments to the presence of mist in the windowpanes and mirrors at bath time: "It [*condensation*] is… when… the windows are full of water vapor."

Additionally, they were able to apply the scientific concept of state change from liquid to gas to explain their everyday experiences. For instance, the presence of water in the breath:

> David: [*We*] Pour our breath on the 'Cloudscope'. That got with water!

Mario: It evaporated! The water from the breath!

Regarding the use of everyday and scientific terms, children used interchangeably "steam" and "smoke" to refer to water in gas state; and "air" and "wind" to refer to air. These findings are aligned with those reported by Johnson (1998), about the indifferent use of the terms vapor, gas and air by older children (11-14 years old). This author suggests the importance of understanding what children mean with these terms, as they do not use them in the same way than adults. In this classroom, the term "particles" was introduced by school videos and pieces of information. Children used instead "drops" to explain representations of particles in their drawings and embodied models. They were able to explain the states of water in their own words, but also appropriated the scientific terms from the class "solid", "liquid" and "gas". In order to refer the processes they used the words "evaporation" and "condensation", as discussed previously.

3) *Peer scaffolding benefits explanation construction*. Providing children with enough time to discuss with their peers and reflect about their experiences benefit the construction of explanations. Along the course of the project, we find that most of the ideas that were discussed between peers were agreed and accepted by the group. The affordances of peers scaffolding have been reported by other studies (e.g. Donato, 1994; Pifarre & Cobos, 2010). The ideas that had not been "discovered" by them or their peers were more difficult to appropriate, despite the teacher's efforts in explaining the processes involved. For instance, the notion of evaporation as little drops that go to the air, introduced by David by the sixth session after carrying out experiment 'Boiling', was eventually accepted by most of children, according to the discourse of those children whose intervention is high and medium and to the drawings discussed in chapter 5. Nevertheless, the teacher struggled to explain to them the notion of condensation as a state change and the effect of temperature and, even though, children were not able to appropriate it. In chapter 7, the teacher and peers scaffolding strategies from ECE1-L to ECE3-L are discussed.

4) *Perception with senses plays a role in children's ability to build explanations*. This finding is consistent with other studies about the importance of perception with senses in early ages, beginning with the

pioneer studies of Jean Piaget (Piaget, 1936; 1947) about the stages of cognitive development. Piaget called the first stage, from birth until 2 years old, the *sensorimotor period*. In this stage, babies only experience the world through their senses. It is not until the *preoperational stage* (2 to 7 years old) that children can internally represent the world through language and mental imagery. In this study, children's explanations about evaporation improved after they were able to *see* the bulk of steam coming out of the kettle and *touched* the water drops. They were more capable to explain that when water evaporates from the kettle ends up in the mirror (visible) than to understand that from the mirror it evaporates into the air of the class (not visible). Accepting the presence of water drops, which are not visible, in the air seems to be one of the most difficult aspects to understand for them. Children enacted models in which they represented the particles' behavior and the teacher provided models to help their visualization of how air could 'hold' substances. Even though children eventually seem to accept this idea, only in certain contexts were they able to relate it to the phenomena observed. For instance, they consistently applied the idea of water drops in the air to explain that evaporated drops go to the air. In a study with 11-14-year-olds, Johnson (1998) reported that the notion of particle can provide children with a mean to visualize how bubbles in boiling water change to gas state. It should be noted that Johnson's (1998) study analyzes data from interviews, and not from the actual participation of children in the practice of building explanations about a phenomenon they are experiencing. Children in our study, which are much younger, could not apply the idea of particles to explain those contexts in which the water drops condensed on surfaces that were suspended in the air, for instance, cloud formation and the experiment 'Making a cloud'. In the context of experiment 'Making rain' inside the 'Ecosystem' model, children were able to point to the evaporation of the water from the plants and the lake inside the 'Ecosystem', and only in one occasion, and strongly scaffolded by the teacher, one child pointed out that these water drops were in the air inside. Even though, he did not explicitly point to a relation between this fact and the water undergoing a state change.

In sum, children's explanations evolved through engagement in the project. They started by recognizing components and phenomena and stating casual relationships learnt in their daily life and, eventually, they were able to account for how phenomena took place and explained them making use of scientific vocabulary. They found easier to account for evaporation than for condensation and recognized the process of evaporation in a greater diversity of contexts. This might be a good starting point to begin with in order to build explanations that are more sophisticated.

7 SCAFFOLDING OF CHILDREN'S ENGAGEMENT IN SCIENTIFIC PRACTICES

This chapter discusses results related to the fourth research objective: *To explore how ECE teachers support children's engagement in scientific practices and how scaffolding changes along the three years of ECE.*

7.1 INTRODUCTION

This chapter aims to explore in which ways teachers scaffold ECE children's engagement in scientific practices, with a focus in how the production of scientific representations is scaffolded differently over the first and last year of ECE. Our hypothesis is that the teachers' scaffolding promotes children's engagement in scientific practices in sophisticated ways. In this sense, the chapter focuses on the teachers' strategies. The research questions that drive the analysis are:

1) Which are the strategies used by the ECE-L and ECE3-P teachers to support children's engagement in scientific practices?

2) Which are the features and affordances of scaffolding children's engagement with scientific representations?

3) How is the intensity of scaffolding modulated from ECE1-L to ECE3-L?

In order to answer the second and third research questions, the analysis was carried out in collaboration with Christina Siry (Monteira, Jiménez-Aleixandre & Siry, in review).

First, participants and context are described. Second, the data corpus and the analysis are presented. Third, results are discussed.

7.2 PARTICIPANTS AND CONTEXT

The participants are the groups of the longitudinal study (ECE-L) (23 children) and of the preliminary study, ECE-P (25 children) and their teachers. The groups and their teachers were engaged in the 'Snails' (ECE1-L, ECE3-P) and 'Clouds' (ECE3-L) projects that lasted for 5 months each, which have been discussed in previous chapters.

7.3 DATA ANALYSIS

In this section data corpus and tools for analysis are presented.

7.3.1 Data Corpus

The study focuses in data from the first and third year of study. For answering the first research question, regarding scaffolding children's engagement in scientific practices, transcripts from the sessions from both groups, ECE-L (31 hours, from both first and third year) and ECE3-P (5 hours), were examined.

In order to answer the second and third research questions, regarding how the production of scientific representations is scaffolded and how the intensity of scaffolding is modulated from ECE1-L to ECE3-L, the transcripts of the sessions (30.5 hours) and the drawings (N=482) from the 21 children (8 girls and 13 boys) who remained both years in the group were examined.

7.3.2 Methods for the Analysis of the Transcripts

In order to answer the first research question, two types of analysis were carried out. First, content analysis to identify recurrent themes; and second, discourse analysis with the purpose of identifying features of ECE-L and ECE3-P teachers' strategies and their interventions in the class talk.

In order to answer the second and third research questions, a discourse analysis of the transcripts from ECE-L was carried out with the purpose of categorizing verbal scaffolding for the drawing tasks, both provided by the teacher and between peers, that Donato (1994) and Moll (1990) call "collective scaffolding".

7.3.3 Methods for the Analysis of the Drawings

Aligned with Sherin, Reiser and Edelson's (2004) ideas about expanding the scaffolding metaphor to learning artifacts, the structural scaffolding provided by the ECE-L teacher in the drawing tasks was analyzed for the purpose of addressing the second and third research questions.

A content analysis (Bell, 2001) of the drawings was carried out, according to these dimensions: type of element (iconic and symbolic), type of drawing technique, and coloring. Part of the results from this analysis, regarding children's engagement with models and representations, has been discussed in chapter 5. In order to analyze the teacher's structural scaffolding, in this chapter we examine who took the decisions, either the teacher or the children, about: a) the contents, as some of them were included as part of a template, fill-in-the blank and cut-and-paste tasks; and b) drawing techniques and coloring; additionally, we examine c) who was cutting and pasting elements.

Due to the great amount of productions collected along the study, and in order to illustrate the findings, five different tasks that convey a range of the dimensions analyzed, from three focal students, were selected and subjected to in-depth analysis. The three focal students, Aitor, Loreto and Mario, have been presented in chapter 5. One more drawing from another student is analyzed in order to illustrate a combination of teacher's scaffolding means.

Additionally, with the purpose of better characterizing the ECE-L teacher's scaffolding, both verbal and structural, we interviewed her about her *goals or intentions*, that is what she wants to achieve with the scaffolding, and the *tools or means* she provided to achieve them, that is how scaffolding takes place (Van de Pol, Volman & Beishuizen, 2010).

7.3.4 Methods for the Analysis of Intensity of Scaffolding in Drawings and Transcripts

In order to answer the third research question, regarding the modulation of scaffolding from ECE1-L to ECE3-L, an analysis was carried out drawing from studies examining the relevance of the intensity of scaffolding in students' performances (Van de Pol, Volman, Oort & Beishuizen, 2015).

Scaffolding can be thought of both as a process and a structure, with three key elements: contingency, fading and transfer of responsibility (Reigosa & Jiménez-Aleixandre, 2007; Van de Pol et al. 2010). *Contingency* refers to the tailored support of student activities; *fading*, to its progressive disappearance or diminution; and *transfer of responsibility*, to the progressively higher learner's control of the learning situation, cognitively, metacognitively or affectively.

Pearson and Gallagher (1983) proposed the Gradual Release of Responsibility Model that involves three phases: 1) teacher, 2) joint, and 3) student responsibility. Although scaffolding intensity could be considered as a continuum, for analytical purposes, three levels, high, medium and low, were established, drawing from Pearson and Gallagher's (1983) notion of release of responsibility from the teacher.

Table 7.1 defines the coding categories for the intensity of verbal and structural scaffolding in this study. In this analysis, it is considered that there is high intensity of scaffolding when the teacher takes the decisions about how and what to draw. For instance, in a detailed template, in which the teacher already drew the elements and children just colored them. It was considered that there is low intensity of scaffolding when she leaves to students the responsibility of taking the decisions about what and how to draw, either individually or through class discussion with peers, called "collective scaffolding" by Donato (1994) and Moll (1990). In between these two extremes, there is a medium-scaffolded situation in which there is joint responsibility. For instance, when children make their drawings without teacher's intervention, and afterwards she cuts them and pastes them into a card.

Table 7.1. Coding categories of the intensity of structural and verbal scaffolding of drawing tasks in the study

Intensity	Structural	Verbal
High	- The teacher provides a detailed template in which children's performance is limited to color the elements depicted or to draw them in a place determined by the teacher - The teacher provides a task in which children's performance is limited to fill-in-the blank and cut-and-paste actions	- The teacher gives very specific instructions about what and how to draw, not promoting children's decisions
Medium	- The teacher intervenes by cutting and pasting a drawing made by the children	- The teacher gives specific indications about one of the elements in the drawing: color/what to draw/where to draw
Low	- The teacher provides a basic template including only a frame, room for drawing and for conclusion: children decide what to write and which elements to draw and where - The teacher chooses only the painting technique	- The teacher's instructions about what to draw are general - The teacher leaves room for children to take decisions through discussion (collective scaffolding)

7.4 Results: Scaffolding children's Engagement in Scientific Practices

This section seeks answers the first research question: *Which are the strategies used by the ECE-L and ECE3-P teachers to support children's engagement in scientific practices?*

First, results from the thematic analysis are discussed, in order to examine how conceptual topics are addressed and reviewed in the course of the science projects. Second, teachers' strategies are discussed.

7.4.1 Recurrence of Topics Addressed

The thematic analysis of the transcripts shows that there was a limited number of topics covered in the projects. In the 'Snails project' there were 11 (ECE1-L) and 12 (ECE3-P) conceptual topics addressed and five of them were reviewed and discussed in several sessions. In the ‘Clouds project’ (ECE3-L) there was a lower number of themes addressed, five, and all of them were reexamined and thought through in more than one session.

Recurrent conceptual issues explored in the ‘Snails project’ are summarized in Table 7.2. They include:

a) Snails’ body model, as their two pairs of tentacles, one of them carrying the eyes, their ribbon-like mouthpiece (“radula”), and their shell.

b) Snails’ biology, as what they eat, their senses, reproduction, growth, excrements and slime’s functions. As discussed in chapter 4, the group ECE3-P was able to explore snails’ healing as well, due to an unexpected accident that took place in the class.

c) Snails’ abilities, such as their ease to pull objects heavier than them and to walk on wires.

As discussed in chapter 4, most of these issues, such as snails’ radula and what they eat were explored through *purposeful observation*. Topics such as the snails’ senses were addressed through experiments that were repeated and reviewed several times. Other issues were examined through second-hand information, for instance, snails’ internal organs that were discussed using a drawing of snails’ inner body plan.

Table 7.2. Recurrence in several sessions for each topic in the ‘Snails project’ (recorded sessions N =6)

Group	Radula	Slime	Alimentation	Shell	Tentacles
ECE1-L	4	4	3	3	3
ECE3-P	5	4	2	2	2

As summarized in Table 6.3, in chapter 6, in the context of the ‘Clouds project’, the issues addressed, from higher to lower recurrence, were: a) state changes; b) cloud formation; c) types of clouds; d) the weather; and e) the water cycle.

Recurrence allowed children to explore in depth content-specific issues, such as snail’s biology or the types of clouds. It made possible the revision of knowledge under the light of new evidence. For instance, recurrence supported children’s modification of their ideas about snails' mouthpiece, and their way of eating, discussed in chapter 4, and the evolution of their explanations about evaporation, discussed in chapter

6. Recurrence allowed for continuity. It should be noted that children's engagement in *purposeful observation* (Monteira & Jiménez-Aleixandre, 2016) is closely related to this continuity, as the affordances of this type of observation have to do with engaging in it for sustained periods of time.

7.4.2 Reflection about Observations, Experiments and Learning

Four different teachers' strategies have been identified in the analysis, summarized in Table 7.3. They are discussed next.

Table 7.3. ECE Teachers' scaffolding strategies

Teachers' Strategy	Characterization
Reflection	The teachers provide children with many opportunities to think back about their observations and experiences, to talk about them and to reformulate their meaning
Supporting Talking Science	The teachers promote epistemic talk about why and how do we know what we know in a safe and supportive environment
Legitimizing Children's Role as Knowledge Producers and their Participation in Science	The teachers acknowledge children's contributions to the project, such as the data they gather or the pieces of information they bring to share with the community, recognizing them as knowledge producers
Promoting Children's Autonomy in Discourse	The ECE-L teacher consistently intervenes in class talk in order to promote children's science talk. Her interventions are tailored and become less frequent from ECE1-L to ECE3-L

By reflection in this context we mean that the teachers' promoted children's reflective thinking by providing them with many opportunities to think back about their experiences and to discuss them, so that they were able to reformulate their meaning. For Dewey (1933, p.18) "*Active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it, and the further conclusions to which it tends, constitutes reflective thought*".

Addressing the same topic several times was a feature of these classrooms. For instance, the following excerpt corresponds to the revision of the topic “radula”, in session 6 in ECE1-L. Only few children are identified in this excerpt because the class was dark, in order to be able to observe the projection of two pictures of the limpet’s radula taken during the previous session. Children were discussing them:

Teacher: Why did we look a limpet’s radula?
Romeo: Because… because it is mollusk!
Teacher: Because it is mollusk, very well, like whom?
Several: The snail!!
Teacher: And snails, as limpets, as sea snails, have radula, right?
Several: Yes!
Teacher: What did Sabela say to us the other day, that this colored things were…
Child: Teeth!
Several: Yellow! Green! Red!
Teacher: Green? Red. But what were they?
Several: Teeth!
Teacher: They were the teeth, right?
Child: And I said it [they are teeth].
Teacher: What do they have… What do they have so many teeth for?
David: For eating!
Teacher: For eating, right, Celia?
Child: For making holes!
Teacher: For making little holes, yes, for being able to yumm, yumm, yumm! For eating, like they eat the lettuce we saw here.
Child: Yumm, yumm.
Teacher: […] To be able to make these holes that they make when they eat, they need to have… what do they have on the tongue?
Several: Radula!
Teacher: No, what do they have?
Child: Teeth!
Teacher: Do we have teeth in our tongue?
Several: No.
Teacher: Where do we have the teeth?
Several: Here [some children point to their mouths]

Original language:
Mestra: Por que miramos a rádula dunha lapa?

Romeo: Porque… porque es molusco!
Mestra: Porque es molusco, moi ben, igual que quen?
Varios: O caracol!
Mestra: E tanto os caracois, como as lapas, como os caracois de mar, teñen rádula, verdad?
Varios: Si!
Mestra: Que nos dicía o outro día Sabela que eran estas cousiñas de color…
Non identificado. Dentes!
Varios: Amarillo! Verde! Rojo!
Mestra: Verdes? Vermello. Pero que eran?
Varios: Dentes!
Mestra: Eran os dentes, verdade?
Non identificado: Y yo lo dije!
Mestra: Para que teñen… Para que teñen tantos dentes na rádula?
David: Para comer!
Mestra: Para poder comer, verdade, Celia?
Non identificado: Para hacer agujeros!
Mestra: Para facer buratiños, si señor, para poder ñam, ñam, ñam! Ir comendo, como comen a leituga que vimos aquí.
Non identificado: Ñam, ñam.
Mestra: […] Para poder facer esos buratos que fan cando comen, teñen que ter… que teñen na lingua?
Varios: Rádula!
Mestra: Non, que teñen?
Non identificado: Dentes!
Mestra: Nós temos dentes na lingua?
Varios: Non.
Mestra: Non. Donde temos os dentes?
Varios: Aquí.

The teacher introduced the topic prompting children to explain why they are observing the radula, with the objective of making sense of the activity and reviewing that both snails and limpets belong to the category of mollusks. Next, she focused on one particular aspect of the radula: its "teeth." She first directed children to discuss to "what" is this part. Second, she demanded children to account for "why snails have teeth". Third, she prompted them to compare it to human mouth. Then, she kept on questioning the children about the aspect of the radula:

Teacher: In the mouth, all around, all around. But in the tongue, our tongue does not have teeth, is not it true? But the snail's tongue does, that is why is called radula, right? […] Let's see another picture, that we have more than one here. Look, do you see it? There it can be seen very well, very well, the tongue is colored how? How is it colored?

Child: Orange.

Teacher: It seems orange, right? It seems orange. […] It looks like…What does it look like?

Child: Like an "S".

Teacher: Like and "S".

Child 1: Like a slug.

Teacher: Like a slug.

Child 2: And like a snake.

Child 3: Like a tail.

Teacher: Like a tail, like an animal's tail.

Original language:

Mestra: Na boca verdad, ao redor, todo o redor. Pero na lingua, a nosa lingua non ten dentes, verdade que non? Pero a lingua dos caracois si, por iso se lle chama rádula, verdade? […] Vamos a ver outra foto, que temos aquí máis de unha. Mirade, védela? Aí se ve moi ben, moi ben, a lingua é o que é de cor… de que cor é?

Non identificado: Naranja.

Mestra: Así laranxa parece, verdade que si? […] Parece un… a que se parece isto?

Non identificado: A unha "S".

Mestra: A unha "S".

Non identificado 1: A unha babosa.

Mestra: A unha babosa.

Non identificado 2: Y a unha serpiente.

Non identificado 3: A una cola.

Mestra: A una cola, a un rabo de algún animal.

It should be noted that, all along this excerpt, she legitimized children's contributions by repeating what they said.

Similarly to the review of topics, reflection about experiments took place not one time, but repeatedly. The experiments were carried out and reviewed several times during each project. For instance, in three out of six recorded sessions of the 'Snails project', children in ECE3-P devoted great part of the time to review the procedures, data generated and conclusions from experiments that had been carried out previously. In ECE1-L they did so in two out of six sessions. In the context of the 'Clouds project' the experiments about state changes were carried out in more than one occasion, as summarized in Table 6.1. For instance, the experiment 'Making rain' was repeated in three different sessions and it was reviewed without carrying it out in another three.

In both classrooms, reflection was very important. The time devoted to discussions and reflections about the experiences and their meaning was substantially more extended than the actual time devoted to carrying out the experiments or the observations.

7.4.3 Supporting Talking Science

The teachers sought the conditions for children to engage in talking science: they promoted epistemic talk by creating a safe and supportive environment in which children were encouraged to discuss *why we know what we know*.

Children did not need to worry about "wrong" answers, and teachers and children listened to each other. This aspect, according to Alexander (2008), characterizes dialogic teaching. As a result, the environment of the class supported students' engagement in talking science.

The teachers prompted children to talk about hypotheses or reminded them that, in order to know something, an investigation is needed. Examples of this type of talk are discussed in chapter 4. For instance, children in ECE3-P claimed that smaller snails were faster than bigger ones. The teacher answered them that: "But we don't know whether this is true or not, we would need an experiment". In another episode, also discussed in depth in chapter 4, the teacher asked the children if snails' teeth were "like ours", and Elena pointed out: "If they have them, we don't know that yet". This type of talk can be illustrated by the following excerpt from session 1 in ECE1-L, while children were discussing which parts of snail they knew:

> Sebastian: And they [*snails*] do not have hair.
>
> Teacher: And they do not have hair. Well, we do not know that, we have not investigated it yet, Sebastian.

Original language:
Sebastián: E non teñen pelo.
Mestra: E non teñen pelo. Ai, iso non o sabemos, inda non o investigamos, Sebastián.

As discussed in chapter 4, the teacher in the ECE3-P group introduced the terms *hypothesis* and *evidence*, which were appropriated by children. The teacher initiated 11 out of the 15 episodes of explicit talk about hypothesis, testing claims and evidence, throughout the six recorded sessions of the 'Snails project'. This emphasis contributed to a commitment to evidence as the epistemic basis of beliefs (Osborne, 2014). In these classrooms, claims need to be supported by evidence, and the teachers consistently require children to back their claims.

7.4.4 Encouraging and Legitimizing Children's Role as Knowledge Producers and Their Participation in Science

Encouraging children's role as knowledge producers involves the teachers' acknowledgment of the value of children's contributions to the project and recognizing their capacity to generate scientific knowledge.

The teachers asked the children to show and describe to their classmates the books and information they brought from home to share with the group. When these pieces of information were reviewed in another session, the teachers made explicit who was the child that brought them, as shown in the following excerpt from ECE3-P:

Teacher: What [*information about a topic*] did Arantxa bring the other day?
Several: Body parts.
Teacher: […] She brought us how were the snail insides. What did we find out? That the snail had…
Arantxa: Heart, *blain* [*brain*]…
Danilo: It is almost like us!
Teacher: What else did it have?
Several: Lungs!

Original language:

Mestra: Que trouxo Arantxa o outro día?
Varios: As partes do corpo.
Mestra: […] Tróuxonos como era o caracol por dentro. E que descubrimos? Que o caracol que tiña…
Arantxa: Corazón, *celebro*…
Danilo: Casi é coma nós!
Mestra: Que máis tiña?
Varios: Pulmones!

The two teachers prompted children to discuss and share knowledge. As seen in the excerpt, the ECE3-P teacher questions served as a stimulus for children to review the topic "snails' internal organs".

In the 'Clouds project' the ECE3-L teacher provided each child with a 'Clouds' Observer' credential and an instrument for using in their observations: the 'Cloudscope'. This instrument consisted in a piece of card with pictures of different types of clouds and a squared hole in the middle through which children framed a part of the sky. Both the credential and the 'Cloudscope' pursued the objective of legitimizing the knowledge produced by children in their observations.

7.4.5. Promoting Children's Autonomy in Classroom Discourse

The promotion of autonomy in children's discourse refers to the tailored ECE-L teacher's interventions in the class talk in order to prompt children to build explanations and support their claims with evidence. In this section, this teacher's scaffolding of children's science discourse along time is discussed. In the second and third results sections this aspect is further explored in relation to children's production of scientific representations. In this group, the teacher interventions in the class talk became less frequent from ECE1-L to ECE3-L: from 48.5% to 42.55% of the total turns of speech. By the third year, in many occasions children spontaneously built explanations, supported their claims with evidence and addressed topics in greater detail than in the first year. We relate these changes in children's performances, on the one hand, to the teacher's strategies that promoted these ways of participating in the scientific practices, and, on the other hand, to the fact that children are two years older and more proficient speakers, so they are capable of building longer and more elaborated sentences. The following two excerpts serve to illustrate this point. They correspond to ECE-L children's first observations of shells and clouds, respectively.

The first excerpt, from ECE1-L, occurs in the context of an observation carried out with the objective of comparing a sea and a land snail shells. Although the children had already observed the land snail shells in previous sessions, this was the first time they observed a sea snail shell in the classroom:

> Teacher: Let's see, guys, difference between this snail [*land snail shell*] and this one [*sea snail shell*]? Shhhh! Rayssa! Difference. Are the shells the same, Loreto?
> Several: No.
> Teacher: What are the differences between them?
> Loreto: They do not have the same color.
> Teacher: They have different colors. What else, Andres, tell me a difference.
> Andres: They are not the same.
> Teacher: Is this shell like this other shell?
> Andres: No.
> Teacher: Why? Tell me, Mario.
> Mario: Because this shell is [*stretched*] like this to the top
>
> Original language:
> Mestra: A ver, chicos, diferencia entre este caracol y este. Shhh! Rayssa! Diferencia. Son iguales as cunchas Loreto?
> Varios: Non.
> Mestra: En que se distinguen?
> Loreto: Que no son de iguales color.
> Mestra: Que son de diferente color. Que más, Andrés, dime una diferencia.
> Andrés: No son iguales.
> Mestra: Esta concha es igual que esta concha?
> Andrés: No.
> Mestra: Por que? Dime Mario.
> Mario: Porque esta cuncha está así para arriba.

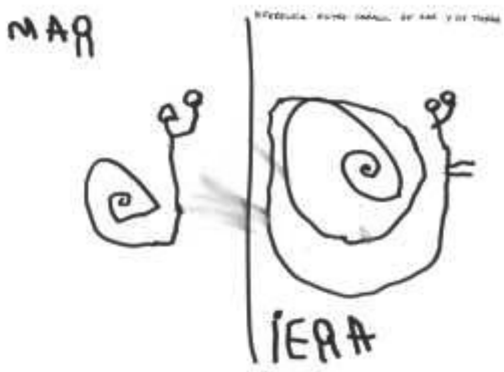


Figure 7.1 Drawing of a land and a sea snail, by Ali (ECE1-L)

It can be noted that children's interventions are short. The teacher demands children to report on the differences in more detail by repeating their words, that is, legitimizing their claims, and questioning them back, for instance, using "what else" and "why" prompts. After the observation, children made a drawing registering differences between both types of snail, from which a sample from Ali is reproduced in Figure 7.1. As most of children, he drew a sea snail with one pair of tentacles (Figure 7.1, left hand side of the sheet), whereas the land snail has two pairs of tentacles and is bigger (on the right). In ECE3-L she still uses the same strategies, but children's interventions are longer and spontaneously engage in building explanations, as illustrated by the following excerpt, corresponding to the first observation of the clouds in the school courtyard:

Teacher: Are they [*clouds*] all the same?
Several: Noooo!
Non-identified: Some are grey and some others are white!
Teacher: And are they close or far away?
Several: Far away! / Close!
[…]
Teacher: And are they [*clouds*] the same than the first time we looked [*at them*]?
Several: Noooo!
The teacher calls children's attention and asks them to stop playing.
Romeo: A white cloud was over there, and now it is not.

Mario: Because it went going down.

Original language:
Mestra: Son todas iguais?
Varios: Nooon!
Non id: Unhas son grises e outras son blancas!
Mestra: E están cerca ou lonxe?
Varios: Lonxe! Cerca!
[…]
Mestra. E estas nubes están igual que cando miramos por primeira vez?
Varios. Nooon!
A mestra chámalles a atención e dilles que deixen de xogar.
Romeo. Una nube blanca estaba ahí y ahora ya no.
Mario. Porque fue bajando.

Children's answers are longer and more detailed than in ECE1-L and spontaneously include evidence to justify their claims, such as explaining that clouds are different because of their coloring or that the clouds do not look the same because a white cloud has moved. It can be noted that the teacher's prompts help children to carry out the observation. She supports them by narrowing the observation focus, pointing to aspects that children are able to understand and manage, because they are known to them, such as the clouds' distance to the ground: "And are they close or far away?" This feature distinguishes "purposely observing" from just "looking at" the clouds. This observation took place in the first session of the project and children did not yet distinguish between *cirrus, stratus* and *cumulus* clouds. The teacher asked children to look for these three types of clouds in the course of the fifth observation, because they had already discussed which observable features could be used to recognize them. For instance, children decided that the clouds of the type *stratus* could be identified because they were the ones that did not allow to see the sky behind them. Figure 7.2 shows children using the 'Cloudscope' to carry out a clouds' observation in the school courtyard.


Figure 7.2. Clouds' observation in the school courtyard

As a summary, it can be said that the main dimensions of teachers' approach to support children's participation in science are: recurrence of topics; promoting reflection about observations, experiments and learning; supporting science talk; acknowledging children's participation in science and their role as knowledge producers; and promoting children's autonomy in discourse. This approach facilitated children's engagement in scientific practices in complex ways, as discussed in previous chapters.

7.5 Results: Features and Affordances of Scaffolding Young Children's Production of Scientific Representations

This section of results answers the research question: *Which are the features and affordances of scaffolding children's engagement with scientific representations?*

First, an overview of the overall results about the ECE-L teacher's scaffolding goals and means is presented. Verbal and structural scaffolding *means* and their corresponding *goals* (Van de Pol et al., 2010) were identified from three data sources: transcripts, children's drawings and interviews with the teacher. Scaffolding goals, according to Van de Pol et al. (2010), can be 1) metacognitive, such as learning purpose and features of a science representation, 2) cognitive, such as learning science contents; and 3) affective, such as keeping children's interest in the tasks. These authors take into account a wide range of scaffolding means: providing feedback, hints, instructing, explaining, modeling, and questioning. In this analysis of means, we focus only on those used to scaffold drawing tasks. The results of this analysis are summarized in Table 7.4.

Table 7.4. Teacher's scaffolding of children's drawings: goals and means

Scaffolding goal	Scaffolding mean
Learning purpose and features of a science representation (metacognitive)	- Providing an experiment representation template that contains: a title and/or central question, a visual representation/model of what is being documented, a short written explanation/conclusion
Learning painting techniques (cognitive)	- Choosing painting tools to be used in each task: watercolor, crayon, marker pen, or tempera painting
Learning to read and to write (cognitive)	- Demanding children to write their own names - Requiring children to write word labels or paste printed words in appropriate order
Learning science contents (cognitive)	- Asking children about the phenomena before representing them - Demanding accuracy in the drawings
Learning to use both iconic and symbolic elements (cognitive)	- Using representations with iconic content and symbolic elements - Designing representation tasks with iconic content and symbolic elements
Learning aesthetic concepts (cognitive)	- Framing templates - Intervening in children's drawings: cut and paste in order to achieve a more aesthetically pleasant aspect - Asking children to apply different decoration techniques: borders and backgrounds
Keeping interest in drawing tasks (affective)	- Acknowledging students' performances when they draw carefully

About *metacognitive goals*, we interpret that the teacher provided the means for children to understand the features of science representations, which is a metaknowledge goal, by giving them a template. Children built scientific knowledge that could be shared with others through representations; for instance, children explained their experiments to the researcher by pointing to the drawings. By designing the experiment templates, the teacher set up the conditions for children to represent in a visual mode, through drawings and texts, both the scientific knowledge built in the class (e.g. drawings that represent concepts) and how it was built (e.g. drawings that represent the procedure of an experiment), in a way that was clear to share with others.

Other scaffolding means used by the teacher are related to *cognitive goals*, such as choosing different painting tools, so that children could learn different techniques or demanding them to write labels, in order to practice writing, as it is their first year of schooling and they are learning to write in.

Before every drawing task, a discussion about the science contents represented took place in order to review the science contents. While doing the drawing, the teacher demanded children to be focused in the task, to reflect about what they were drawing and to pay attention to accuracy in their representations.

The teacher introduced in the class representations that combined a range of symbolic and iconic elements. It should be noted that, although the teacher did refer to "symbols" when she answered the researcher's questions about the symbolic elements included in the drawings and the representations used in the class, she did not employ the terms *symbolic* and *iconic*, which we draw from literature, as discussed in the methods section. She fostered children's interaction with representations that included both types of elements since ECE1-L. For instance, the two columns display in which children pasted the pictures of the food that the snails ate and did not eat, which are iconic elements. The symbolic elements of this display were the smiling and sad face on the top of each column. In ECE3-L they discussed a poster of the water cycle that included a color code for distinguishing between evaporating and precipitating water drops (symbolic elements); and in which there were plants, mountains, rivers, clouds and the Sun depicted (iconic elements). The teacher also designed drawing tasks that demanded the use of both, as drawing S5 discussed in chapter 5, that included iconic elements such as the snail, the flour and the salt; and symbolic elements, such as the color code and the union lines. As a result, children got acquainted with the use of symbols, that they used in their own drawings to represent the phenomena under study.

Regarding the support of children's learning of aesthetic concepts, the teacher was keen in demanding children to be "neat" when drawing, often providing first a pencil for making a draft before doing the final drawing with pen. In occasions she intervened in children's drawings, for instance, cutting and painting. She provided children with frames in the templates and asked them to apply different decoration techniques in different tasks, in order to children become proficient with a variety of them.

About *affective goals*, the teacher always publicly acknowledged student's efforts at producing representations; and prompted children to share them with the rest of the group, encouraging them and keeping their interest in the task.

As a summary of results, it can be said that in the course of the projects, the teacher combined a range of the scaffolding means listed above that were adjusted to each goal, whether metacognitive, cognitive or affective. Regarding children's performances in achieving teacher's learning goals when producing the representations (with scaffolding), these are illustrated with examples from the selected tasks in the third section of results, which addresses modulation of scaffolding from ECE1-L to ECE3-L.

7.6 RESULTS: MODULATION OF SCAFFOLDING OF REPRESENTATION TASKS ALONG ECE

This section discusses results for the third research question: *How is the intensity of scaffolding modulated from ECE1-L to ECE3-L?*

As discussed in the data analysis section, scaffolding can vary in intensity. In our use of the term *modulation*, we consider how the intensity of scaffolding is adapted to each task, which implies combining different intensity in structural and verbal means. Three levels of intensity, high, medium and low, characterized in Table 7.1 (data analysis section) were identified.

The teacher varied the intensity of scaffolding in a non-linear way along the years of the study, as summarized in Table 7.5. In ECE1-L, the intensity of structural scaffolding was high for 6 tasks, medium for 8 and low for 4. In ECE3-L, it was high for 3 tasks, medium for 1 and low for 5. The intensity of verbal scaffolding in ECE1-L was high for 2 tasks, medium for 11 and low for 5; whereas in ECE3-L was high for 2 and low for 7.

Table 7.5. Intensity of structural and verbal scaffolding in drawing tasks from ECE1-L (N=18) and ECE3-L (N=9)

Intensity of scaffolding	ECE1-L, N=18		ECE3-L, N=9	
	Structural	Verbal	Structural	Verbal
High	6	2	3	2
Medium	8	11	1	-
Low	4	5	5	7

Although the changes in the intensity of scaffolding did not follow a trend from one task to the next in all the cases, for five of the scaffolding goals summarized in Table 7.4, the fading of scaffolding was linear, from high to low. These scaffolding goals, discussed below, are: learning the purpose and features of a science representation, learning painting techniques, learning to write and read, and learning to use both iconic and symbolic elements and aesthetic concepts.

Regarding the goal of *learning features and purpose of science representations*, experiment templates can be considered a scaffolding structure that remains constant while being flexible (Walqui, 2006). The teacher in this study incorporated a culture of observation and documentation, and she began to provide scaffolds to 3-year-olds, so that children learnt to document in a particular format. Specifically, she sought to have pupils be able to construct productions that included structures consistent in format, including:

- having a title and / or central question

- a visual representation / model of what is being documented (an experiment, a concept, an experience)

- a short written explanation of what was observed

- aesthetic elements, such as a border around the edge of the paper and drawings that occupy much of the space.

In ECE1-L, the experiment templates provided by the teacher were more detailed than in ECE3-L. Along the two instructional units, the room for the drawing and for the conclusion in the templates remained constant, as well as the frame, but not the contents of the drawings. In ECE1-L the teacher decided what the content should be, or directly had them depicted in the template. This emphasis by the teacher on what the content should be in the children's drawings accounts for the lower individual differences in what is represented in the first year. This strategy allowed the teacher to introduce an array of symbols that children learnt to recognize and use, meeting the scaffolding goal of *learning to use both iconic and symbolic elements*. In ECE3-L, the children took the decisions about what elements to represent and they drew both icons (e.g. a glass) and symbols (e.g. water drops evaporating). They also engaged in explaining the meanings of the symbols in their representations, as discussed in chapter 5.

Regarding the scaffolding goal of *learning to read and to write*, by the first year the teacher gave to the children words that made up the conclusion, or word labels to paste in the appropriate place; and she asked them to label the elements depicted by writing the name of each of them. Every time children were asked to order words or engaged in a fill-in-the-blank task, a discussion preceded the activity in order to take decisions about what to write and paste.

Progressively, the teacher allowed collective scaffolding to take more room, and teacher's scaffolding faded out. By the third year children already had the ease to read and to write, and the teacher was not that keen anymore about writing labels with the name of the contents depicted in every drawing. As a consequence, the content analysis of ECE3-L drawings reveals much more individual differences in the presence of labels within the same task, as it is children's choice. For instance, seven children decided to write the name of the equipment they used for the experiment 'Boiling' in their drawing and eleven did not, as shown by Figures 7.3, with equipment labels: "water", "water met[e]r", "mirror", "smoke" (original language : "agua", "me[t]ro de agua", "espejo", "humo"; in capital letters) ; and 7.4, without them, and only with the conclusion of the experiment. By the first year, the teacher provided the words that made up the conclusions, to paste them in order; whilst by the third year the conclusions were collectively decided by the children through class discussion and, afterwards, they wrote them down on their own.

Figure 7.3 Drawing of experiment 'Boiling' with equipment labels. Conclusion text: "We learnt the water steam" (original language: "Aprendimos el vapor de agua")

Figure 7.4 Drawing of experiment 'Boiling' without equipment labels. Conclusion text: "We l[e]arnt the water steam" (original: "Ap[re]ndimos o vapor de agua")

Regarding the scaffolding goal of *learning aesthetic contents*, the teacher progressively released control in children's hands. In ECE3-L she does not intervene in children's drawings anymore because they are already able to cut and to paint with different tools, but she keeps the frames as part of the templates and keeps on asking them to decorate with borders.

Regarding the scaffolding goal of *learning painting techniques*, the teacher chose the techniques that she wanted children to learn. In ECE1-L there is a greater variety of techniques represented in the children's drawings than in ECE3-L, as for the first year her objective was introducing to the children different tools so they could practice with all of them.

For the remaining two goals, the scaffolding did not fade. About *learning science contents*, scaffolding remained consistent as the teacher kept asking the children for accuracy. Regarding *keeping children's interest in drawing tasks*, she continued acknowledging their performances, which is seen as evidence for supporting children's interest in the drawing tasks.

Figure 7.5. Drawing representing the relation between the color of snail's excrements and the colors of the food they eat

The drawing that represents the relation between snail's excrements and the food they eat (Figure 7.5) serves for the purpose of illustrating a variety of scaffolding goals and means. This drawing is a fill-in-the-blank task in which many symbols are embedded. The drawings have a color code that stands for the relation between the food and the color of snails' excrement, although the pieces of food appear in different order for different children. Children decided, through collective scaffolding, the color with which they were going to paint the snail's excrements and which piece of food should be pasted underneath. In loud voice, they said the name of each piece of food, and the teacher asked them to write labels for them. After the children finished the drawings, the teacher wrote the complete words beside, in order to make them understandable for the families. The teacher asked Romeo to explain his drawing to the researcher. As discussed before, as part of her didactic strategy, she acknowledged the role of children as producers and communicators of knowledge. Romeo explained that: "When they [*snails*] eat tomato, the poo comes out red, when they eat lettuce, the poo comes out green and when they eat fish and flour, white poo".

The modulation of scaffolding intensity in the drawings is illustrated next with drawings from the focal students. As discussed above, the teacher modulated the intensity of scaffolding from the first to the third year of ECE and adapted it to each task.

The drawings of snail's radula, S8 (Figures 5.17, 5.18 and 5.19) and limpet's radula, S17 (Figures 5.20 and 5.21), from ECE1-L, were scaffolded with medium intensity. The teacher intervened choosing the painting tools and cutting and pasting elements drawn by children into a final document for each child. The painting tools were different in S8 and in S17, so that children could practice with watercolor and tempera, respectively. In order for children to practice writing, the teacher asked them to label the drawings with the words *radula* (S8) and *limpet's radula* (S17).

The drawings of three states of water, C6, were made in ECE3-L (Figures 5.29, 5.30 and 5.31), and this was one of the tasks supported with high intensity of scaffolding: the teacher decided both the structure and the contents. She asked the children to divide a blue sheet of paper in three sections and to write the labels *solid*, *liquid*, and *gas* on the top of each column in order to represent each one of the three states underneath. As it can be observed in the selected drawings, Figures 5.29, 5.30 and 5.31, in the little space children were left with for taking decisions, they did draw differently. The painting tools used in this drawing, and in all but one (C1) of those made during the course of the 'Clouds project' in ECE3-L, were the same. Children used first a pencil and then, colored marker pens.

Regarding how the teacher modulated the intensity of scaffolding for some of the learning goals, drawings S5 and C5 serve for the purpose of illustrating these changes (see Table 7.6).

Table 7.6. Changes in scaffolding means in experiment templates: S5 and C5

Scaffolding intention	Scaffolding Mean		
	Both S5 and C5	S5	C5
Learning purpose and features of a science representation (metacognitive)	The teacher provides an experiment template	The template is detailed and only allows children for coloring the contents	The template is basic, only contains a frame and room for conclusion and drawing
Learning painting techniques (cognitive)		The teacher choses painting tools	The teacher allows children to decide painting tools
Learning to read and to write (cognitive)	The teacher takes some decisions about the texts and for the remaining allows children to take them through collective scaffolding	The teacher provides labels with the words that makes up the conclusion sentence and children decide how to order them The teacher asks for writing labels	The teacher asks children to write a conclusion and children decide which one
Learning science contents (cognitive)	The teacher asks the students about the phenomena before representing it The teacher asks for accuracy in the drawings		
Learning to use both iconic and symbolic content (cognitive)		The teacher decides both the iconic and symbolic elements in the drawing The teacher asks children to use symbols of her choice	The teacher lets children decide which iconic and symbolic elements to draw
Keeping interest in drawing tasks (affective)	The teacher acknowledges students' performance		

For both drawing tasks children were provided with experiment templates. Drawing S5 (Figures 5.14, 5.15 and 5.16) was highly scaffolded. The central space for the drawing was already filled by the teacher with the snail, the flour, the salt and the pathways. Drawing C5 (Figures 5.22, 5.23 and 5.24) also has a frame, with space for the drawing and for the conclusion, but children chose what to draw in it.

The fading of teacher's scaffolding regarding the goal of *learning to read and to write* can be also noticed in these drawings. In S5, children were left the responsibility of ordering the labels they were given with the words that make up the conclusions. In C5, the responsibility of producing a conclusion claim was entirely transferred to the children. As adressed in chapter 5, through discussion, children validated one of their peers' proposals: *We saw how water evaporated*. All the drawings but one contain this conclusion. It was written entirely by the children, which accounts for slight differences in wording: "*We saw how water evaporated"*/"*Water evaporated"*. One child also added: "*and went to the sky".* The teacher asked them to write labels in S5, whilst in C5 she did not.

As a summary, it can be said that the teacher combined tasks with varying intensity of scaffolding along both years. Her scaffolding means were adequated to her goals, designing the drawing tasks in such a way that the intensity of scaffolding was progressively reduced for some of these, for instance learning to write and to learn; whilst for others, such as learning scientific contents, it remained constant.

7.7 Discussion

This chapter examines teachers' strategies as, through consistent scaffolding, they provided the means and conditions necessary to support children's engagement in scientific practices in complex ways, as discussed in previous chapters. The teachers in this study create a rich learning environment characterized by: a) long-term scientific projects; and b) a particular type of scaffolding that is modulated from ECE1-L to ECE3-L. This chapter seeks to give an insight into how teachers may introduce scientific practices in early childhood classrooms, as it has been reported to be challenging for K-1 teachers (Merritt, Chiu, Peters-Burton & Bell, 2017). It has a focus on the practice of using and producing models and representations, to which the ECE-L teacher pays special attention, and which are central to the construction of science. As Gilbert (2010, p. 2) points out "Representations are the entities with which all thinking is considered to take place. Hence they are central to the process of learning and consequently to that of teaching."

Five interconnected teaching strategies identified as relevant for supporting children's engagement in scientific practices are: 1) recurrence, 2) reflection; 3) supporting science talk; 4) encouraging children's role as knowledge producers and their participation in science; and 5) promoting their autonomy in discourse. These features of the teachers' approach are closely related to the design of the projects, specifically to the fact that they involve learning about a science content along extended time. These five strategies are discussed next.

Recurrence: over all the sessions, projects focused on a few questions and topics. They were addressed along several sessions and reviewed in the light of new evidence. This recurrence, illustrated for instance in the findings of chapter 4 regarding the revision of children's ideas and drawings of mouthparts, provides continuity through the project. It may have an influence similar to the effect of science journals reported by Gelman and Brenneman (2012), "(to) solidify their understandings because they provide a chance for learners to think again about a science experience" (p. 166). Mere observation does not lead to change, unless there is reflection about data, theoretical claims and their connections.

Reflection: one feature of the teachers' approach is to provide children with many opportunities to think back about their observations and experiences, to talk about them and to reformulate their meaning. Engaging students in discussions about their observations is a feature highlighted by Zangori, Forbes and Biggers (2013). In this study, the time devoted to these discussions and reflections was substantially longer than the actual time devoted to carrying out the experiments or the observations.

Supporting science talk: discourse in these classrooms involved explicit talk about how we know what we know (and, in the case of

ECE3-P, introducing the terms *evidence*, *hypotheses*, *claim* and *testing*, as discussed in chapter 4). The teachers put an emphasis on the need for providing evidence in order to make a claim. It is worth noticing the differences between children in first an third year of schooling. In ECE3-L and ECE3-P, children have been with the same teachers for three years, so they were used to be asked to justify their claims and they did so spontaneously, whilst in ECE1-L the teacher had to prompt children for them to provide pieces of evidence to back their claims. Features of the teachers' approach, such as prompting students to identify evidence, or providing hints about evidence and claims, are similar to the ones discussed by Gotwals et al. (2012).

Encouraging and legitimizing children's role as knowledge producers and their participation in science: these classrooms' environment is supportive, so children are comfortable with sharing their ideas, without worrying about mistakes. Children became engaged in the subject through joint exploration with the teacher. Their contributions to the projects, such as representations of the topics under study; or the pieces of information they bring from home or gather through observation are highly valued by the teachers and children are prompted to share them with the group. Bruner has stated that the most effective motivation is the actual pleasure of learning, not getting a good school mark: "experience success and failure not as reward and punishment, but as information" (Bruner 1961, p. 26).

Promoting children's autonomy in discourse: the ECE-L teacher interventions in the class talk became less frequent from ECE1-L to ECE3-L. In order to pursue the increasing autonomy of children, she consistently intervened in the talk, for instance, with 'why' and 'how' prompts, until children spontaneously included justifications for their claims and engaged in building explanations.

Regarding children's increasing autonomy in producing scientific representations from ECE1-L to ECE3-L and the increasing complexity of these (the latest discussed in chapter 5), they can be closely related to the teacher's scaffolding. A range of didactic goals she aimed to achieve by scaffolding the drawing tasks was identified. Didactic goals were metacognitive, such as learning purposes and features of a scientific representation; cognitive, such as learning to use iconic and symbolic types of content; and affective, such as keeping children's interest in the tasks. For achieving these, she used a range of means, both structural, such as experiment templates, and verbal, such as acknowledging the children. The variety of scaffolds for drawing tasks that the teacher used does indeed seem to reach most of the children over time. As she consistently scaffolded over time, when she faded the scaffolds, the children still met her expectations.

Regarding how scaffolding was modulated from ECE1-L to ECE3-L, her use of scaffolds was not necessary linear, in that she did not always go from high scaffolding down to low over time, but rather scaffolded when and as needed to meet the task. For some of the scaffolding goals, though, she faded the intensity of scaffolding from ECE1-L to ECE3-L. Children became increasingly more autonomous, being able to meet teacher's expectations on their own. For instance, the intensity of scaffolding for experiment templates in ECE1-L was very high. In many of them, children's intervention was limited to color the contents and paste in order the words that made up the conclusion sentence. Two years after, in the lower scaffolding conditions, children were given basic templates for representing the experiments and still met the teacher's requirements about science representations, such as having a central drawing, including details that represent the findings, the experimental procedure or both, and having a conclusion decided and written by them. It should be noted that achieving a high degree of autonomy has been found to be difficult even for older students (Reigosa & Jiménez-Aleixandre, 2007). These young children were able to meet the teacher's expectations for engaging in the practices of science, and also, over time and with scaffolding, were able to do it by themselves and even suggest their own approaches and scaffold their peers. Scaffolding also had affective results. The teacher kept encouraging children to participate and acknowledging their efforts and contributions to the project, such as sharing thoughts, experiences and bringing information from home.

The teacher created the space for those who have different interests and abilities – but still kept fairly uniform expectations for all children over time. As she drew away the higher levels of scaffolding over time, the children demonstrated that they were able do these tasks without so intense scaffolding, and in doing so bring multiple other foci to their work. Even in the higher scaffolding conditions we see evidence of how children bring themselves into the drawing, for instance in C6, states of water: even though the teacher decided the structure and the elements represented, children found ways to bring themselves in, such as representing the water drops in different dispositions or using a color code.

Children's engagement in scientific practices goes hand-by-hand with the teachers' strategies. The teachers' scaffolding favored children's sophisticated performances, as discussed in previous chapters; and paved the way for them to become more autonomous from first to third year of schooling, as examined in-depth in chapter 5. We agree with other authors (Gelman & Brennemman, 2012; Metz, 2008; 2011) that adequate learning environments have a deep effect in facilitating the development of the capabilities of young children. As other researchers acknowledge (Andersson & Gullberg, 2014; Inan & Inan, 2015), the teacher's role is especially relevant in early ages. These teachers' scaffolding promotes a type of science learning in which both contents and construction of knowledge are integrated, consistently, along time. Progressively, children take greater responsibility and awareness of their learning, because the teachers design the conditions with these purposes. The implementation of the projects begins in such a way that children can participate actively in them since the beginning with a certain degree of autonomy. For instance, by bringing an animal that is known for them, the snail, children are able to contribute by sharing what they already know; and then, start to build knowledge, in cooperation, according to their interests. Thus, children's contributions are recognized and the knowledge they generate is valued, which promotes their participation in science. The type of classroom discourse fostered in these classrooms conveys explicit reflection about how they built scientific knowledge and in which pieces of evidence this is based. The affordances of promoting this type of discourse structured around explicit argumentation have been acknowledged (NRC, 2007). In sum, the teachers' scaffolding strategies are purposeful directed towards learning goals that have a positive effect in children's increasing autonomy to engage in authentic and complex ways in doing science and participating in science discourse. As Sinatra and Taasoobshirati (2011, p. 214) point out: “By promoting reflection, cooperative inquiry, critical thinking, and tailoring instruction to promote engagement and conceptual change, science classrooms can support the development of motivated, goal-directed, self-regulated learners”.

III. CONCLUSIÓNS

8 CONCLUSIONS

This thesis aims to analyze the ways in which children in Early Childhood Education engage in scientific practices and how this engagement evolves from first to third year of Early Childhood Education (ECE). The participants are: the group of the longitudinal study (ECE-L), another group in third year of ECE (ECE3-P) and their teachers. This aim is explored through four overarching research objectives: three of them regarding children's performances and one regarding the teachers' strategies.

Objective 1. *To explore the features of Early Childhood Education children's engagement in using evidence and what is the role of purposeful observation in this practice.* This objective is addressed through the following research questions, all discussed in chapter 4:

1) In which ways do children in early childhood use evidence and how is this use reflected in the development of data into evidence? What are the differences in the use of evidence between first and third year of ECE? Conclusion 1 refers to the first question and Conclusion 2 to the second.

2) Which ways of gathering empirical evidence are jointly constructed by children and their teachers during the project? Which is the role of observation in this context and which are its features? What are the differences in gathering evidence between first and third year of ECE? Conclusion 3 refers to the first question, Conclusion 4 to the second and Conclusion 5 to the third.

3) How do children use evidence to revise their understandings? What are the differences between first and third year of ECE in the

revision of understandings under the light of new evidence? Conclusion 6 refers to the first question and Conclusion 7 to the second.

Objective 2. *To explore what features has children's use and construction of models*, *what is the role of representations in this practice and how it evolves from ECE1-L to ECE3-L.* This issue is examined through three research questions, all addressed in chapter 5:

1) Which science meanings about snails are constructed and communicated by ECE1-L children in their expressed models and how do they change during the year? Conclusion 8 refers to this research question.

2) Which communicative and representation resources of the science classroom community are appropriated by ECE1-L children? Conclusion 9 refers to this research question.

3) How do children's ways of engagement with scientific expressed models become increasingly more complex from ECE1-L to ECE3-L? Conclusion 10 refers to this research question.

Objective 3. *To explore which are the features of building explanations in ECE3 and how this practice evolves along a school year.* This objective is addressed through the following research question discussed in chapter 6:

What are the features of ECE3-L children's explanations about state changes and how do they evolve along the school year? Conclusions 11, 12, 13 and 14 refer to this research question.

Objective 4. *To explore how ECE teachers support children's engagement in scientific practices and how scaffolding changes along the three years of ECE.* This objective is addressed through three research questions, all discussed in chapter 7:

1) Which are the strategies used by the ECE-L and ECE3-P teachers to support children's engagement in scientific practices? Conclusion 15 refers to this research question.

2) Which are the features and affordances of scaffolding children's engagement with scientific representations? Conclusion 16 refers to this research question.

3) How is the intensity of scaffolding modulated from ECE1-L to ECE3-L? Conclusion 17 refers to this research question.

Next, the conclusions drawn from each research question are summarized. Then, educative implications, limitations and directions for future research are discussed.

8.1 Conclusions

Conclusion 1. In this study, we have identified two processes in the development of data into evidence, previous to those reported in studies in primary education (e.g. Songer & Gotwals, 2012; 2013). These two processes are: (1) selecting data appropriate for being transformed into evidence related to a claim; and (2) identifying potential (appropriate) evidence that could confirm or disconfirm a claim. Both processes are scaffolded in our study. We suggest that studies about early childhood and primary schooling should identify descriptive statements or *raw data*, alongside argumentative components, such as evidence, in order to better document how the transition from data to evidence occurs. We define raw data as description of first-hand observation, experiment or second-hand information, but unrelated to a claim or to a question. Children in this study use and generate evidence to support their claims and answer their own questions.

Conclusion 2. Complexity in children's use of evidence increases from ECE1 to ECE3. Children in ECE3-P supported their claims with evidence more frequently than children in ECE1-L: 20,6% and 15,44% respectively. Evidence statements have been distributed according to their sophistication. The coding scheme draws from Aikenhead (2005) and from Duschl's (2008) first critical transformation in the E-E continuum. It distinguishes two levels of epistemic judgment. In level 1, statements closer to data; and in level 2, statements involving evaluative judgments meeting one of these criteria: (a) identifying patterns in data; (b) connecting data and claim through justifications; (c) establishing comparison with other data; (d) explicitly evaluating one or several alternative claims. Most of the evidence statements both in ECE1-L (75%) and in ECE3-P (64%) belong to level 1. The discourse of children in ECE3-P includes a higher proportion of evidence statements that involve evaluative judgments: 36% were coded as level 2 in ECE3-P; and 25% in ECE1-L. In this study, we have not found evidence that ECE1-L children were able to identify patterns nor explicitly evaluate several alternative claims, although they were able to connect data and claim through justifications and to establish comparison with other data.

Conclusion 3. Young children are able to gather and generate data from these sources: experimentation, observation and information search. In both groups, ECE-L and ECE3-P most of the evidence collected was empirical first-hand data, either through experimentation or through purposeful observation. According to previous studies (Delen & Krajcik, 2015; Hug & McNeill, 2008), first-hand data evoke a higher sense of ownership in students. Regarding the design and interpretation of the experiments, children planned them, with strong input from their teachers, in order to seek answers to their own questions. They posed hypothesis and appropriated the notion that the results of the experiments could be used to test them. Nevertheless, they found difficulties in producing appropriate hypothesis. For instance, they produced hypothesis that could not be tested through experimentation. Often, they found difficulties in distinguishing conclusion and justification, which is consistent with previous studies, even at older ages.

Conclusion 4. *Purposeful Observation* plays an important role in young children's engagement in science, particularly in the

generation of first-hand data. We define *purposeful observation* (Monteira & Jiménez-Aleixandre, 2016), as a prolonged, systematic observation that has a clear focus; it is guided by the teacher, recorded and explicitly discussed. Findings from this study reveal its potential as a source of evidence in ECE. It allowed children to gather first-hand data and follow processes, such as the healing of a broken shell. The majority of the evidence statements (both level 1 and level 2) correspond to the context of purposeful observation: 30 out of 57 in ECE3-P and 32 out of 45 in ECE1-L.

Conclusion 5. Evidence from *Purposeful Observation* takes more room in the construction of evidence by younger children. In ECE1-L, 7 out of 11 evidence statements codified as level 2 correspond to evidence generated through purposeful observation. In ECE3-P, evidence statements codified as level 2 were distributed among the three sources: 7 correspond to purposeful observation; 6 to experimentation and 8 to secondary data. The prevalence of purposeful observation as a source of evidence in ECE1-L can be related to the fact that it might be an easier practice to engage in at these ages than experimentation. For children in ECE3-P, engagement in experimentation provided an explicit frame for the relations between claim and evidence.

Conclusion 6. Children in ECE are able to use evidence from *purposeful observation* in the revision of their ideas. In the course of the project about snails, an investigation about snail's mouthparts emerged in both ECE1-L and ECE3-P from children's first observations of the marks that the snails left in food, observations which were incorporated by the teachers to the inquiry about snails. Along the course of the project, children gathered data about the snail's mouthparts, mainly through purposeful observation, although they also used data generated by themselves in experiments and obtained through information search. Changes in children's models about the snail's mouthparts were expressed by their drawings and talk. These evolved from an initial anthropomorphic model of mouth, with "teeth" and "tongue", to a final model that they described and depicted as a thin and elongated organ that snails take in and out of their mouth to eat.

Conclusion 7. The main differences between both age groups, ECE1-L and ECE3-P, in the revision of their ideas, are related to the level of detail in the mechanisms proposed and to the use of vocabulary, rather than to children's ability to use evidence to change their models. Both groups constructed the concept of "radula" according to evidence and proposed mechanisms to account for how snails use it to eat. The mechanism proposed by ECE3-P children was more detailed than the one proposed by the younger ones. Children in ECE3-P described the radula as a long and rough organ with spikes and indicated that snails spin it in order to scrape off food. Children in ECE1-L defined the radula as a long and thin "tongue" with "teeth" all around, and, in order to account for how the animal uses it, they took their tongue in and out. It should be noted that the younger children used the words "teeth" and "tongue", as well as "radula", because they conceptualized the organ through its functions. These are parts of the human body that children know well; and they built their models starting from what is known for them. As Inagaki and Hatano (2006) acknowledge, human-based inferences or person analogies are useful for biological understanding, and should be viewed positively.

Conclusion 8. Children express their science understandings through their drawings, which reflect changes in their ideas. The analysis of the contents represented in two series of drawings of snails from ECE1-L made within a month of difference shows changes in children's models of snails. Although individual choices differed and drawings present many differences among them, the two series of representations of a snail follow a trend: they became less anthropomorphic and children incorporated new parts of the snail's body, or represented others that were dealt with during the project with more salience or higher accuracy, for instance, the two pairs of tentacles. In the construction of these external representations, children's mental and expressed models interacted, as shown by the rectifications made by children in the process of drawing them.

Conclusion 9. Children appropriate communicative resources from the classroom, in addition to science meanings, and these are reflected in their drawings. Children in ECE1-L were in their first year of schooling and, as part of their enculturation in the school science community, they were exposed to a range of visual communicative resources. They interpreted, appropriated and used these resources in their representations. Through these resources, children:

- Communicated the type of modality of their drawings, such as scientific or artistic.

- Connected and disconnected elements in their drawings, indicating the relationships between them. For instance, separating in one drawing the snail (purpose of the drawing task) and their own name (class' rules for identifying productions), as they belong to two different categories.

- Accounted for the relative importance of the elements depicted. For this purpose, children used semiotic resources as salience, saturation or displacing. For example, snail's slime was highlighted by saturation (six drawings) and by displacing it (two drawings).

- Used compositional resources that reveal that they are appropriating written communication and aesthetic awareness. For instance: they placed in the center the nucleus of the information, produced the elements of the drawing from left to right, or distributed them harmonically, occupying most of the space of the sheet.

Conclusion 10. Children's ability to engage in modeling practices increases from ECE1-L to ECE3-L. Children in ECE-L engaged in modeling practices in 27 out of the 30 sessions examined. The evolution in children's engagement with models and representations takes place in several dimensions:

-Children became able to engage in a greater variety of modeling practices as they progressed in the ECE years. In ECE1-L children often needed support from the teacher in order to be able to interpret representations. They engaged mainly in using (8 times) and producing (5 times) models. In ECE3-L the proportion between these two types of practices is more balanced: children engaged in using and producing in

17 and 20 times, respectively; and they also engaged once in evaluation of models. Gradually, they became more autonomous and did not need so much support from the teacher.

- During the first year, children mostly engaged with visual models, whilst by the third year they engaged with models expressed in visual, gestural and physical modes. The use of a diversity of semiotics modes can be useful to reach children with diverse perspectives.

- In the third year, children engaged in metaknowledge talk about models. For instance, they discussed how the features of a phenomenon were conveyed by a given representation, often spontaneously and they did not need so much teacher's support to engage in this type of talk. Vice versa, they discussed how they could represent the phenomena.

- From ECE1-L to ECE3-L children became proficient at interpreting and including both iconic and symbolic elements in their representations. In ECE1-L, the teacher introduced all the symbolic and most of the iconic elements. By ECE3-L children were able to decide and draw on their own which ones to include in the majority of their drawings. As a consequence, the content analysis regarding which elements were depicted by children in each drawing task shows much more differences in ECE3-L than in ECE1-L. Iconic elements, such as representations of observable entities, for instance a kettle, were depicted in greater detail in ECE3-L.

- Children appropriated visual codes that could be used to communicate meanings to others. In ECE1-L, the teacher introduced these codes, such as connecting lines. By ECE3-L children were able to create their own symbolic elements, such as color codes.

- Regarding the *representational* meaning (Kress & Van Leeuwen, 1996) conveyed by children's visual representations, drawings in ECE3-L tend to be more technical than in ECE1-L. In ECE3-L children decided what elements they depicted and how. They also made more *conceptual* drawings than *narrative* ones. In ECE3-L a majority of children did not depict people carrying out the experiments, but the entities and processes involved in them.

Conclusion 11. Children in ECE3-L recognize components and processes and propose explanations about state changes. Before they started to study state changes, children were able to recognize some of the processes involved and to relate them to factors such as temperature. Along the course of the project, children were also able to propose explanations about how the processes took place and to relate models to phenomena. The teacher supported children's construction of explanations by promoting their reflection, reviewing and repeating the experiments and pointing to key aspects of phenomena. Children's ability to build explanations about evaporation and condensation differed. They were able to recognize evaporation phenomena and to apply their explanations about it in a greater variety of contexts than for condensation phenomena.

Conclusion 12. Everyday and scientific school knowledge interact in children's explanations. Children brought with them everyday knowledge and vocabulary about state changes that they mobilized and related to classroom experiences. Children's explanations emerged from the interaction between both sources of knowledge.

Conclusion 13. Peer scaffolding benefits explanation construction. Most of the ideas that were discussed between peers were agreed and accepted by the group. The affordances of peer scaffolding have been reported by other studies (e.g. Pifarre & Cobos, 2010). The ideas that had not been "discovered" by them or their peers were more difficult to appropriate, despite the teacher's efforts in explaining the processes involved.

Conclusion 14. Perception with senses is a key factor in young children's ability to construct explanations about natural phenomena. Children's ability to interpret and explain evaporation improved once they were able to observe a bulk of boiling water coming out of a kettle and to touch the condensed water on the mirror placed above it, realizing that it was water. They found difficult to understand the presence of not observable substances in the air. Eventually, they partly accepted that evaporated water "drops" could be in the air even though they were not visible. This understanding seems to be related to the context: they did not apply this notion to consider condensation of water in the air.

Conclusion 15. Long-term projects and teacher's scaffolding promote children's engagement in scientific practices in sophisticated ways. Long-term projects, both in ECE1 and ECE3 allowed children to explore in depth a small number of topics, which were recurrent along the sessions. Recurrence has to do with *purposeful observation*, as its affordances are related to engaging in it along a sustained period. Several teachers' strategies are combined in the course of the projects:

- Reflection: that is, providing children with opportunities to think back and reflect about their experiences.

- Supporting talking science, which involves promoting epistemic talk about the construction of knowledge and how it can be supported by evidence.

-Legitimizing children's role as knowledge producers and their participation in science: children shared pieces of information, drawings and observations with the community, which were positively valued by the teachers. The teachers explicitly acknowledged children's interest and capacity as knowledge producers.

-Promoting children's autonomy in classroom discourse: the interventions of the ECE-L teacher in the class talk were tailored with the purpose of promoting children's autonomy in science talk. Her interventions became less frequent from ECE1-L to ECE3-L, as children engaged spontaneously in building more detailed explanations and backing their claims with evidence.

Conclusion 16. The combination of verbal and structural scaffolding means has metacognitive, cognitive and affective affordances in children's production of scientific representations. The ECE-L teacher pursued a series of learning goals that she achieved by combining different scaffolding means:

- The teacher provided children with experiment representation templates, so they could learn the purpose and features of scientific representations, which is a metacognitive goal. These templates contained a title, room for a visual representation and for a conclusion, so that the message could be could be shared with others and clearly understood.

- She pursued the following cognitive goals: first, learning to write and to read, for which she demanded children to write their names and word labels, or to paste printed words in appropriate order. Second, in order to learn science contents, she demanded children to be accurate in their scientific representations and prompted them to discuss the phenomena before representing it. Third, in order to children became proficient at using both iconic and symbolic elements; she introduced them and designed representation tasks that involved the use of both. Fourth, she pursued children's learning of aesthetic concepts by: intervening in their drawings, in order to make them more aesthetically pleasant, framing templates and asking children to apply an array of decoration techniques. Fifth, in order to support children's learning of different painting techniques she chose different painting tools (e.g. tempera, watercolor) to be used in the drawing tasks.

- She fostered children's interest in the drawing tasks by acknowledging their performances, which is an affective goal.

According to the analysis of children's drawings, the adjustment of each mean to its learning goal reached the majority of children and had positive effects in their performances and increasing autonomy along time.

Conclusion 17. The progressive decrease along time of the intensity of the teacher scaffolding benefits children's gains and promotes their autonomy and their ability to scaffold each other. The teacher's scaffolding was adapted to each task and its intensity is not linear, as she combined high and low intensity of scaffolding along both projects. Nevertheless, for some learning goals, the intensity of scaffolding decreased, allowing children to take more responsibility as they became increasingly more autonomous: collective scaffolding between peers took more room in detriment of the teacher's scaffolding. As scaffolding was progressively withdrawn, children were able to meet the teacher's expectations for the task in the conditions of lower intensity of scaffolding.

- The experiment templates in ECE3-L were less detailed than those in ECE1-L. They contained room for the drawing, the conclusion and a frame. Children decided which iconic and symbolic contents they wanted to draw. In ECE1-L the teacher provided them with very detailed templates, in which children's intervention was limited, in some cases, only to color the iconic and symbolic elements drawn by the teacher.
- Regarding the conclusion text in the experiment templates, in the first year the teacher provided them with the word labels that made the conclusion text. The order in which these were pasted was decided through collective scaffolding. By the third year, she did not provide it anymore and children helped each other in elaborating and deciding an appropriate conclusion.
- In ECE1-L the teacher demanded the children to include word labels for the elements depicted in their drawings in order to learn to write. By ECE3-L this was children's choice, as they were already able to write.
- In ECE1-L the teacher intervened in children's drawings, and in ECE3-L she did not do it anymore. Children were already able to decorate the drawings on their own having learnt aesthetic notions.
- The variety of painting techniques used in ECE1-L was much higher than in ECE3-L, because the teacher decided the painting tools and she wanted children to be able to use different ones.
- The teacher's scaffolding regarding learning science contents and keeping children's interest in the task did not decrease in intensity from ECE1-L to ECE3-L.

8.2 EDUCATIONAL IMPLICATIONS

The following educational implications are drawn from the conclusions of this study:

From Conclusions 1 and 2 addressed in chapter 4, regarding the use of evidence by young children, the findings suggest the relevance of documenting the development of data into evidence in order to develop instructional programs that support children's engagement in the use of evidence from early ages. For this purpose, it is relevant to identify descriptive statements or raw data, in addition to evidence, claim and justification. This would facilitate the development of argumentation learning progressions for which the two first levels would imply: (1) selecting data appropriate for being transformed into evidence related to a claim; and (2) identifying potential (appropriate) evidence that could confirm or disconfirm a claim. In both levels, ECE children would need to be scaffolded.

From Conclusions 3, 4, 5, 6 and 7 addressed in chapter 4 educational implications would be the convenience of integrating purposeful observation in ECE classrooms. It facilitates children's active engagement, supports their engagement in core scientific practices, such as argumentation, and provides a way for children to evaluate and revise their own ideas. The evaluation and self-regulation of their own ideas is essential for autonomous learning. Thus, it is important to provide children with learning environments that allow them to do so since early ages. We suggest the importance of promoting purposeful observation as a source of evidence in kindergarten and in the first years of elementary education, in particular, in life sciences because it supports students in collecting and interpreting data, in the transformation of data into evidence, and in using evidence in order to revise their understandings. Purposeful observation is complementary to investigations and experiments; it poses, perhaps, fewer difficulties for young children. As research shows, even adolescents have problems when planning investigations (Jiménez-Aleixandre & Crujeiras, 2014). What we are proposing is to use them in combination, not to focus only on purposeful observation; however, we suggest that in early ages purposeful observation should be given more emphasis. The identification and characterization of *purposeful observation* is a novel and original contribution from this study, which has been published in the *Journal of Research in Science Teaching* (Monteira & Jiménez-Aleixandre, 2016), and chosen as "Research that matters" from 2016 by a joint NSTA / NARST committee.

Difficulties related to the explicit evaluation of evidence from purposeful observation by children, point to the interest of designing instruction in such a way that the generation of data from purposeful observation and its role in building evidence-based claims is framed more explicitly. Experiments provide a frame where the relations between claim and evidence are more explicit and clear-cut from the beginning. In the case of purposeful observation, the claim may be derived from evidence, emerge later in the process, and the relations may be more diffuse. It should be noted that our suggestion is to combine experiments and purposeful observation, rather than to focus only on the second.

From Conclusions 8, 9 and 10 addressed in chapter 5, regarding children's engagement with models and representations, educational implications would be that instructional design should provide opportunities for children to engage in the modeling practices in sophisticated ways, as, with support, they are able to do so. This type of instruction would embrace different types of practices, such as use, production and evaluation of models and representations. Our findings point to the importance of promoting explicit discussion regarding the purpose and features of representations. Children's ability to visualize would be favored by the inclusion in the classroom of models expressed in a variety of semiotic modes.

From Conclusions 11, 12, 13 and 14, addressed in chapter 8, regarding children's engagement in building explanations, educational implications are that ECE children are able to start building explanations to make sense of natural phenomena, such as state changes, that could serve as a basis for building more sophisticated ones. Results from this study point to the importance of including in the instructional design time for discussing these experiences with peers, making sense of them and establishing relations, supported by the teacher. Children's capabilities to explain natural phenomena can be supported with the design of experiences that are perceptible with the senses, or, if not possible, providing children with visual or physical models that account for non-observable features of the phenomena.

From Conclusions 15, 16 and 17 addressed in chapter 7 regarding the teacher's scaffolding strategies, the following educational implications are drawn:

First, long-term science projects should be included in the ECE classrooms, as they have affordances in supporting children's engagement in scientific practices. This is consistent with recommendations from the literature (Duschl, 2008).

Second, a narrow focus on a few topics and recurrence along the sessions facilitate learning them in depth. This recurrence, illustrated in the findings with the revision of children's ideas and drawings of mouthparts, discussed in chapter 4, provides continuity through the project and may have an influence similar to the effect of science journals reported by Gelman and Brenneman (2012), "(to) solidify their understandings because they provide a chance for learners to think again about a science experience" (p. 166). Mere observation does not lead to change, unless there is reflection about data, theoretical claims and their connections.

Third, reflection about experiences should be promoted as it helps children's revision of understandings. We suggest providing children with many opportunities to think back about their observations and experiences, to talk about them and to reformulate their meaning. The notion of purposeful observation is closely related to reflection. Mere observation does not lead to change, unless there is reflection about data, theoretical claims and their connections.

Fourth, children's ways with science benefit from engaging in science talk about how and why knowledge is built. This emphasis contributes to a commitment to evidence as the epistemic basis of beliefs (Osborne, 2014).

Fifth, the teachers should legitimize children's role as valid knowledge producers as this supports their engagement in science. This implies encouraging and acknowledging their efforts and contributions, such as sharing thoughts, experiences and the information they bring from home.

Sixth, children's age should not be a constraint to promote their engagement in scientific practices in complex ways. Instead, tailored scaffolding along time can facilitate the achievement of sophisticated learning goals.

8.3 LIMITATIONS OF THE STUDY AND FUTURE LINES OF RESEARCH

The limitations of the study are mostly related to its nature, particularly to the constraints of carrying out a longitudinal study in educational research.

On the one hand, along the three years there were variations on the number of students in the ECE-L group. On the other hand, assistance in ECE is not compulsory and the absences were frequent. None of these factors can be controlled. They were recorded in order to have both factors into account for the selection of data for analysis and the interpretation.

Regarding data collection, the first year of study there were communication issues with the teachers, for whom it took a time to understand our need to be in the classroom in most sessions devoted to the project, so not all the sessions of the 'Snails project' were accompanied, missing some of the context, which is one limitation of this study. These issues were overcome for the next two phases of data collection (next two school years), and the group of the longitudinal study was accompanied along the whole science project. This has become one of the strengths of this investigation, as this extended time accompanying the group allowed to build in-depth understandings of the context under study. Thus, it made possible to interpret from a broader perspective the actions, discourse and productions of the participants in the study.

There is another issue derived from the design of the study. It is not an intervention study, as the main aim is to generate knowledge about how real ECE classrooms engage in science. The decisions regarding the design of the science project and their contents are entirely the teachers' responsibility. As a consequence, they vary considerably from year to year. In order to solve this issue, data analyzed in depth were those from the first and third year, because ECE-L children's ways with the project shared more features, which made possible to compare their performances. The design of the project did influence which types of practices could be addressed in the analysis, as the projects provided different opportunities to engage in each of them.

Additionally, the specific objectives of the study were limited by the design, as it determined that the age groups' performances compared were: a) ECE1-L and ECE3-P for the use of evidence; and b) ECE1-L and ECE3-L for the evolution in the engagement with models and representations.

Another limitation derived from the different nature of the projects, is that the contents covered in the 'Snails project' and in the 'Clouds project' were different, which might have had an effect children's performances.

Due to the nature of case studies, the results discussed in this thesis cannot be generalized, as the purpose of this type of design is to produce knowledge about the learning processes and contexts through detailed analysis.

In relation to the findings of this thesis, two differentiated lines for future research can be drawn: a first one about children's performances; and a second one concerning the teachers' practices.

Regarding children's performances, the vast data corpus allows for carrying out complementary analysis from different perspectives. A potential focus of analysis would be the role of emotions in science learning at young ages, which has been pointed out as a key factor by other authors (Fleer, 2013; Siry, 2014). Our data reflect that, across the sessions, children have different attitudes that vary according to the contents under study, the activities and the context in which they are immersed. Children's productions, such as their drawings, also reflect different interests, aside from the science contents.

Non-verbal interactions, such as gestures and gazes, have not been addressed in this study. It has been found that part of the children do not participate in the class discourse very often, although most of them show proficiency in practices such as production of representations that reflect their understandings. Therefore, it would be of great interest to account for how these children experience the science class and in which ways they interact with their peers and teacher. This interest in exploring multimodal communication in the classroom is inspired by other works such as, for instance, Gómez-Fernández, Siry & Wilmes (2017) and Kress (2001). Results of such an analysis could have affordances regarding the design of instruction that could embrace a diversity of children's interests and abilities.

A line of research regarding the teachers' practices and professional development in cooperation with the teachers who participate in this study would be of great interest. There is concern about how educative research can best impact actual practice. This interest is reflected in the literature (e.g. McKenney, 2017) and in the thematic lines of recent conferences in educational research (for instance, one of the lines of the *10th International Conference on Research in Science Education 2017,* organized by the Spanish Journal *Enseñanza de las Ciencias*, was "How to reduce the gap between research and teaching practice?"). According to the literature, reflecting about their own teaching practices has affordances in supporting professional development (e.g. Danielowich, 2007). Further work with the teachers could focus in their reflections regarding their own professional practices. Reflection can also benefit the formation of pre-service teachers. Siry and Martin (2014) studied the reflection in a class of pre-service teachers through the interpretation of videos of their teaching *practicum*. They found that cogenerative dialogue played a role in connecting theory and practice. This design could be adapted for further research with the teachers in our study. New approaches to both research and practice could be developed from a joint work, and transferred to the classroom.

We hope that the results from this thesis contribute to expand the existing knowledge about the ways in which young children generate scientific knowledge through engagement in scientific practices and how their teachers can support this engagement.

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Resumo

O desenvolvemento das prácticas científicas de construción e uso de modelos e probas: un estudo lonxitudinal en educación infantil

Obxectivos de Investigación

O obxectivo da tese é examinar como participa o alumnado de educación infantil nas prácticas científicas e como evoluciona esta participación ao longo da etapa, de primeiro a terceiro curso de educación infantil. Na última década, incrementouse o número de traballos que consideran a ciencia como un conxunto de prácticas de natureza social (e.g. Osborne, 2014). Existe un interese crecente en coñecer como o alumnado participa nas prácticas epistémicas, que se reflicte tanto na investigación (e.g. Chinn, Buckland & Samarapungavan, 2011) coma nos documentos curriculares (e. g. National Research Council, NRC, 2012). Este estudo insírese nesa corrente e, en consecuencia, analízase como o alumnado constrúe coñecemento científico nun determinado contexto social, a aula de educación infantil e como son construídos e comunicados os significados conforme á cultura desa comunidade.

A orixinalidade e pertinencia deste estudo radica en que, por unha banda, existen poucos estudos sobre a participación de alumnado destas idades nas prácticas científicas e, por outra banda, lévase a cabo un estudo lonxitudinal, acompañando a un grupo durante toda a etapa de educación infantil, o que permite seguir a evolución da súa participación nas prácticas, así como unha análise en profundidade do contexto e accións dos participantes no estudo.

O obxectivo foi desglosado en catro obxectivos máis precisos. Os tres primeiros refírense ao alumnado, mentres que o último refírese ás estratexias das docentes.

O primeiro obxectivo de investigación é:

Examinar que características ten o uso de probas polo alumnado de educación infantil, como evoluciona ao longo da etapa, e cal é o papel da observación cun propósito neste uso de probas.

Foi expandido nas seguintes preguntas de investigación:

1) Que características ten o uso de probas polo alumnado de educación infantil e como se reflicte este uso no desenvolvemento de datos en probas? Cales son as diferenzas no uso de probas entre primeiro e terceiro curso de educación infantil?

2) Que formas de obter probas son construídas conxuntamente polo alumnado e as mestras durante o proxecto? Cal é o papel da observación cun propósito neste contexto e cales son as súas características? Cales son as diferenzas nas formas de obter probas entre o alumnado de primeiro e terceiro curso de educación infantil?

3) Como usa as probas o alumnado de educación infantil para revisar as súas ideas? Cales son as diferenzas no uso de probas para revisar as súas ideas entre o alumnado de primeiro e terceiro curso de educación infantil?

O segundo obxectivo de investigación é:

Examinar que características ten o uso e construción de modelos polo alumnado de educación infantil, como evoluciona esta construción ao longo da etapa, e cal é o papel das representacións nesta práctica.

É abordado mediante as seguintes preguntas de investigación:

1) Que significados científicos sobre os caracois son construídos e comunicados polo alumnado de primeiro de educación infantil (3-4 anos) nos seus modelos expresados e como cambian ao longo dun curso?

2) Que tipos de recursos comunicativos e representacionais da clase de ciencias son apropiados polo alumnado de primeiro de educación infantil?

3) Como evolucionan en complexidade as formas en que o alumnado usa e constrúe cos modelos científicos expresados de primeiro a terceiro curso de educación infantil?

O terceiro obxectivo de investigación é:

Examinar que características ten a construción de explicacións polo alumnado de 3º curso de educación infantil e como evoluciona ao longo dun curso escolar.

É abordado na seguinte pregunta de investigación:

1) Cales son as características das explicacións do alumnado sobre os cambios de estado en terceiro curso de educación infantil e como evolucionan ao longo do curso escolar?

O cuarto obxectivo de investigación é:

Examinar como apoian as mestras a participación do alumnado nas prácticas científicas e como cambia este apoio (andamiaxe) ao longo da etapa.

Abórdase mediante as seguintes preguntas:

1) Cales son as estratexias empregadas polas mestras de ECE-L e ECE3-P para apoiar a participación do alumnado nas prácticas científicas?

2) Cales son as características e os beneficios de andamiar a construción de representacións científicas en educación infantil?

3) Como é modulada a intensidade da andamiaxe de ECE1-L a ECE3-L?

Marco Teórico

A Perspectiva Socio-cultural da Aprendizaxe. Este estudo sitúase nunha perspectiva que considera que a aprendizaxe ten unha natureza dialóxica (Bruner, 1966; Vygotsky, 1978). Contemplamos a aprendizaxe máis como un proceso social que individual, mediado polas interaccións sociais nun contexto dado, no que os aspectos culturais e sociais inflúen no que se aprende e en como se aprende. A linguaxe ten un rol crítico no desenvolvemento cognitivo, xa que é o medio polo que é transmitida máis frecuentemente a información de adultos a nenos; permite a comunicación entre pares; e media o pensamento interno dunha persoa (Vygotsky, 1991). Bruner (1996) apunta que a aprendizaxe é un produto cultural e considera que son os membros dunha comunidade quen constrúen significados mediante a negociación, mediada pola linguaxe. Brooks (2005) considera que os debuxos das nenas e nenos tamén son mediadores da aprendizaxe porque serven para comunicar, negociar e construír significados.

Vygotski (1978) propuxo que a aprendizaxe ten lugar no que denominou zona de desenvolvemento proximal (ZPD), comprendida entre o que una persoa é capaz de facer por si mesma e o que é capaz de facer guiada por unha persoa máis experta. Dentro da teoría socio-cultural da aprendizaxe, esta guía coñécese como andamiaxe (scaffolding) (Wood, Bruner & Ross, 1976). Os elementos clave da andamiaxe son a modulación ou continxencia, o esvaecemento e a transferencia de responsabilidade (Reigosa & Jiménez-Aleixandre, 2007; Van de Pol, Volman & Beshuizen, 2010). A continxencia ou modulación refírese á continua avaliación da persoa aprendiz por parte da docente para poder adaptar a andamiaxe ás súas necesidades. O esvaecemento, á desaparición progresiva da andamiaxe. A transferencia de responsabilidade refírese ao maior control por parte do aprendiz e menor control por parte da mestra ou mestre.

A Aprendizaxe das Ciencias en Educación Infantil. Tense afirmado que as nenas e nenos son naturalmente curiosos e realizan observacións e preguntas sobre o mundo que os rodea, de xeito que están predispostos para aprender ciencia (Cabe Trundle, 2015; Patrick & Mantzicopoulos, 2015). Fleer e Pramling (2015) puntualizan que é necesario axudalos a fomentar esa curiosidade para apoiar a súa participación en ciencias. As nenas e nenos fan uso das súas experiencias cotiás para explicar o mundo que os rodea, moitas veces de xeito consistente (Hadzigeorgiou, 2015). Fleer e Pramling (2015), apuntan que os conceptos cotiás, construídos polos nenos a partires das súas experiencias do día a día, son centrais para que nenas e nenos desenvolvan conceptos científicos. Segundo Vygotsky (1978), o desenvolvemento de ambos tipos de conceptos vai unido.

Nos últimos anos, incrementouse o interese por coñecer como o nenas e nenos de educación infantil constrúen coñecemento científico en contextos formais (e.g. Siry, Brendel & Frisch, 2016; Ergazaki, Alexaki, Papadopoulou & Kalpakiorie, 2014) e non formais (e.g. Plummer & Ricketts, 2016); por desenvolver programas educativos innovadores (e.g. Preschool Pathways to Science (PrePS), Gelman & Brennemman, 2012; Science Literacy Program (SLP), Samarapungavan, Mantzicopoulos & Patrick, 2008); ou por coñecer a motivación das nenas e nenos e as posibles diferenzas de xénero no seu interese e rendemento en ciencias (e.g. Leibham, Alexander & Johnson, 2013).

As Prácticas Científicas. O coñecemento científico pode ser considerado unha construción cultural: "A cultural-historical reading of science education would position science as a form of cultural knowledge that is historically and collectively formed and understood, rather than as something that is located within the individual" (Fleer & Pramling, 2015; p. 10). Segundo Kelly (2008) as prácticas epistémicas da ciencia son os modos específicos nos que os membros da comunidade científica producen, avalían e comunican o coñecemento. As prácticas epistémicas e as prácticas científicas están estreitamente relacionadas entre sí e solápanse, especialmente no contexto da aula: "we can think of epistemic practice as a broader construct and of scientific practices as epistemic practices in the context of specific learning contexts or content areas" (Jiménez Aleixandre & Crujeiras, 2017, p.70).

Un informe da Organización para a Cooperación e o Desenvolvemento Económico (OECD) (2012) indica que a participación en ciencias desde educación infantil ten unha influencia positiva no rendemento do alumnado de 15 anos nesta área. Isto apunta á importancia de fornecer de oportunidades para participar nas prácticas da ciencia ao alumnado de menor idade. A literatura indica que as nenas e os nenos son capaces de participar en ciencia, desenvolvendo pequenas investigacións (Metz, 2008; 2011); e poden xerar coñecemento científico mediante as súas interaccións (Siry, 2014). É importante documentar como participa o alumnado de menor idade nas prácticas científicas, co obxectivo de deseñar ambientes de aprendizaxe que lles permitan desenvolver as súas capacidades. Porén, o número de traballos sobre como nenas e nenos de educación infantil participan nas prácticas científicas é moito menor que sobre niveis educativos superiores. Por exemplo, nunha revisión sobre Model Based Learning (MbL), Louca e Zacharia (2012) localizaron poucos estudos en primaria e ningún en niveis inferiores sobre como modelizan as nenas e nenos. Posteriormente, estes autores publicaron un estudo que se centrou nas fases seguidas polas nenas e nenos de 5 anos ao implicarse en modelización (Louca & Zacharia, 2015). En canto á práctica de argumentación, Gotwals, Hokayem e Wright, (2014), documentaron que nenas e nenos de 5 anos, con oportunidades de aprendizaxe apropiadas, poden apoiar as súas conclusións con probas. Sobre como o alumnado de educación infantil constrúe explicacións, Siry e Max (2013) documentaron como o alumnado de educación infantil construíu explicacións de certa sofisticación nun currículo mediado polos seus intereses. Leuchter, Saalbach e Hardy (2014) concluíron que as explicacións sobre flotación do alumnado de educación infantil melloraron despois da instrución cun currículo innovador.

A Semiótica Social da Comunicación Visual. O campo da semiótica ten como obxecto de estudo os símbolos ou signos que permiten a comunicación entre individuos. No contexto da aula, as interaccións discursivas son multimodais: teñen lugar a través da combinación de diferentes modos semióticos, como comunicación verbal ou visual (xestual, escrita) (Kress, Ogborn & Martins, 1998). A aprendizaxe implica a construción de significados, polo que pode ser considerada como un proceso de produción de símbolos, a través do cal os nenos, segundo as súas escollas, "refán" o que o profesor comunica (Jewitt, Kress, Ogborn & Tsatsarelis, 2001). O proceso de produción de símbolos implica facer escollas baseadas en aspectos culturais, históricos, sociais e contextuais (Kress & Van Leeuwen, 1996). O significado dos símbolos varía segundo o grupo social que os produce e comunidades distintas interprétanos dun xeito diferente.

Gran parte dos datos analizados nesta tese son os debuxos do alumnado. A fin de ampliar a comprensión do rango de significados simbólicos contidos nos debuxos, esta perspectiva permítenos acceder á gramática visual utilizada nelas (Kress & Van Leeuwen, 1996). Kress e Van Leeuwen (1996) extrapolan o significado que o termo gramática ten na linguaxe para a súa aplicación en enunciados visuais, nos que a colocación e combinación dos elementos que compoñen a imaxe producen significados. Segundo eles, a elección de recursos semióticos, como a disposición dos elementos, divisións e conexións entre eles, ou a súa relación coa persoa que ve a imaxe, está baseada en supostos culturais. Segundo Jewitt e Oyama (2008): “Social semiotics of visual communication involves the description of semiotic resources, what can be said and done with images (and other visual means of communication) and how the things people say and do with images can be interpreted” (p. 134).

Metodoloxía

A metodoloxía é cualitativa (Merriam, 2009). No que constitúe o estudo central da tese, acompañamos un grupo durante os tres anos da etapa de educación infantil, co propósito de examinar a evolución da participación de nenas e nenos nas prácticas científicas dos 3 aos 6 anos de idade, seguindo un deseño de estudo de caso lonxitudinal (Menard, 2008), apropiado para este obxectivo. Adicionalmente, tómanse datos noutro grupo do mesmo colexio, durante terceiro curso de educación infantil.

O deseño implica a inmersión da investigadora nas aulas mentres levan a cabo proxectos de ciencia de longa duración. Informouse á dirección do centro e ás familias da finalidade da investigación e do uso dos datos. Ao principio de cada curso escolar, pedíuselle autorización escrita á dirección do centro e aos titores legais do alumnado, ao tratarse de menores de idade, para acompañar e gravar as aulas. A fin de protexer a identidade dos participantes no estudo, mestras, nenas e nenos de ambos grupos son identificados mediante pseudónimos que respectan o seu xénero e orixe étnica.

No primeiro ano de estudo (curso 2013/2014) acompañouse aos dous grupos; e no segundo (2014/2015) e terceiro (2015/2016), ao grupo do estudo lonxitudinal, ECE-L. O outro grupo, que chamaremos ECE3-P (preliminar), foi estudado durante o primeiro ano do estudo, en terceiro curso de educación infantil. As mestras de ambas aulas forman parte dun grupo profesional de seis mestras de educación infantil que cada ano levan a cabo un proxecto de ciencias diferente nas súas aulas. O proxecto do primeiro ano desenvolveuse durante cinco meses e forneceu ao alumnado de oportunidades para responder a cuestións formuladas por eles mesmos; e para apoiar as súas conclusións a partir de datos obtidos mediante observación, experimentación e procura de información. Por esa razón, examinamos a práctica de argumentación en base a probas no contexto deste proxecto. O proxecto do segundo ano maioritariamente implicou actividades de observación e representación; e ningunha de experimentación. No contexto do proxecto do terceiro ano, tamén de cinco meses de duración, nenas e nenos tiveron múltiples oportunidades de realizar observacións e deseñar experimentos. Xa que os proxectos do primeiro e terceiro ano permitiron que nenas e nenos tomaran parte nunha maior diversidade de prácticas científicas, centrámonos nestes dous cursos escolares para a análise da evolución da súa participación nestas.

Na investigación cualitativa existen varios tipos de estratexias de recollida de datos, sendo os relevantes para o noso estudo: a observación participante, as entrevistas, a análise do discurso e a análise documental. Os datos recollidos abranguen distintos tipos, o que permite a contrastación: graváronse en vídeo as sesións, recolléronse as producións do alumnado, entrevistouse á mestra e tomáronse notas de campo. Antes e durante a implementación de cada proxecto, asistiuse a reunións co grupo de mestras.

Os tipos de datos analizados en profundidade son as transcricións das sesións de aula (35,5 h) e os debuxos do alumnado (N=680). O foco neste tipo de datos débese a dúas razóns de diferente natureza: por unha banda, as interaccións discursivas e as representacións (debuxos) teñen un rol destacado na construción do coñecemento (e.g. Bruner, 1996; Fleer & Pramling, 2015). Por outra banda, seguindo os principios da investigación cualitativa e, particularmente, do deseño escollido, o estudo de caso, os métodos de análise adáptanse á realidade baixo estudo. Consideramos que, debido á súa frecuencia e á súa natureza, ambos tipos de datos son relevantes nestas aulas para examinar os significados creados polos participantes no estudo.

As transcricións foron examinadas mediante análise de discurso (Gee, 2005). Mediante a interacción entre os datos e a literatura, identificáronse compoñentes da conversa argumentativa (Jiménez-Aleixandre & Erduran, 2008); das explicacións (McNeill, 2011); e de modelización (Schwarz et al., 2009). A partir da identificación destes elementos, desenvolvéronse rúbricas de análise. En interacción coa literatura sobre andamiaxe (Van de Pol et al., 2010), identificáronse as estratexias de andamiaxe verbal empregadas polas mestras para apoiar a participación do alumnado nas prácticas. Ademais, leváronse a cabo análises de contido das transcricións para a identificación dos temas recorrentes ao longo das sesións. En canto á anáise dos debuxos, levouse a cabo (1) análise comparativa do contido (Bell, 2001) e (2), análise semiótica social (Kress & Van Leeuwen, 1996). Estas dúas análises poden considerarse complementarias, xa que permiten acceder á información dos debuxos desde diferentes perspectivas. A análise comparativa de contido céntrase no que se representa, mentres a semiótica social céntrase en como se representa.

Resultados

Os resultados indican que as nenas e nenos participan nas prácticas científicas de uso de probas, uso e construción de modelos e construción de explicacións, con crecente autonomía e complexidade a medida que avanzan na etapa de educación infantil. A continuación, os resultados son discutidos en referencia a cada obxectivo de investigación.

En relación ao primeiro obxectivo de investigación, identificamos dous procesos na transformación de datos en probas, previos aos documentados por outros estudos en educación primaria (e.g. Songer & Gotwals, 2012; 2013). Estes dous procesos son: (1) seleccionar datos apropiados para transformalos en probas relacionadas cunha conclusión; e (2) identificar probas (apropiadas) para apoiar ou refutar unha conclusión. Ambos procesos son andamiados no noso estudo. Suxerimos a pertinencia de identificar raw data, xunto con outros compoñentes da argumentación, como probas, para documentar en profundidade como ten lugar a transformación de datos en probas. Definimos raw data como descricións dunha observación, experimento ou información secundaria e que non están relacionadas cunha conclusión ou pregunta.

No discurso de ambos grupos, ECE1-L e ECE3-P, identificamos máis conclusións que probas usadas para apoialas, o cal é consistente con outros estudos sobre niveis educativos superiores (e.g. Jiménez-Aleixandre, Bugallo & Duschl, 2000). Este aspecto vai mellorando a medida que se avanza na etapa. O alumnado de ECE3-P é capaz de apoiar as súas conclusións con probas con maior frecuencia que o de ECE1-L.

En interacción dos datos coa literatura, foi elaborada unha rúbrica de codificación do uso de probas por parte do alumnado, na que definimos dous niveis de complexidade. O primeiro nivel implica o uso de probas en enunciados próximos a descricións. O segundo nivel implica a avaliación das probas, de acordo a un dos seguintes criterios: a) identificación de pautas nos datos; b) conexión de datos e conclusión mediante unha xustificación; c) comparación con outros datos; e d) avaliación explícita dunha ou máis conclusións alternativas. A capacidade de avaliar probas incrementa a medida que avanzan na etapa. No discurso de ECE3-P encontramos un maior número de enunciados argumentativos que implican a avaliación das probas que no de ECE1-L. O alumnado de ECE1-L foi capaz de conectar datos e conclusións mediante xustificacións e de establecer comparacións con outros datos; porén, non foi capaz de detectar pautas nin de avaliar explicitamente unha ou máis conclusións alternativas.

Os dous grupos obtiveron probas mediante experimentación, observación cun propósito e a partir de fontes de información secundarias. A caracterización da *observación cun propósito* (Monteira & Jiménez-Aleixandre, 2016) é unha contribución orixinal desta tese. Definímola como un tipo de observación prolongada no tempo, cun foco determinado, andamiada, discutida e utilizada para apoiar conclusións e revisar teorías. Nos dous grupos, a maioría das probas foron xeradas mediante observación cun propósito. En ECE1-L a observación cun propósito ten maior presenza na xeración de probas que en ECE3-P. Isto pode deberse a que a observación cun propósito tal vez sexa unha práctica máis accesible a estas idades que outras como a experimentación. A medida que avanzan na etapa, a experimentación fornece dun marco no que as relacións entre probas e conclusións son explícitas, mentres que no caso da observación cun propósito esta relación pode non ser tan clara. De ser así, esta dificultade pode ser superada facendo explícitas as relacións entre os datos obtidos mediante observación cun propósito e as conclusións que apoian.

As probas obtidas mediante observación cun propósito foron usadas polo alumnado para a revisión dos seus modelos da boca do caracol.

En relación ao segundo obxectivo de investigación, os resultados indican que o alumnado de primeiro de educación infantil representa as aprendizaxes construídas durante os proxectos de ciencias mediante os seus debuxos, que poden ser considerados modelos expresados (Gilbert, Boulter & Elmer, 2000). Os cambios nas ideas do alumnado reflíctense nos seus debuxos. A análise comparativa do contido (Bell, 2001) das dúas series de debuxos dun caracol, feitas cun mes de diferenza, revela unha tendencia á construción de modelos menos antropomorfos. Na primeira serie de debuxos abundan as representacións de caracois antropomórficos con extremidades e faccións humanas. Na segunda serie, encontramos modelos de caracol nos que se inclúen novas partes e outras se representan con maior atención ao detalle; como a cuncha, o pe e un ou dous pares de tentáculos. Cando nenas e nenos están inmersos no proceso de producir os debuxos, estes interaccionan cos seus modelos mentais, de maneira que os revisan.

Ademais dos contidos de ciencias, os debuxos do alumnado de primeiro curso de educación infantil reflicten a apropiación de recursos comunicativos da aula de ciencias. A semiótica social da comunicación visual (Kress & Van Leeuwen, 1996) fornécenos dunha perspectiva de análise que, ademais de permitirnos explorar os contidos representados, permítenos acceder este tipo de recursos. Nenas e nenos usan nos seus debuxos recursos como a prominencia, para indicar a importancia relativa dos diferentes elementos que inclúen nos seus debuxos; e son capaces de suxerir relación entre eles e de comunicar a modalidade (artística ou científica) dos seus debuxos. A composición revela que están aprehendendo a comunicación escrita. Dado que en educación infantil, sobre todo nos primeiros anos, a capacidade de comunicarse verbalmente de forma precisa é limitada, os debuxos son unha ferramenta de comunicación moi importante, polo que é conveniente interpretalos de maneira que poidamos acceder aos significados que os nenos constrúen neles, moitas veces complexos, coa maior precisión posible. A semiótica social da comunicación visual revélase como unha perspectiva de análise apropiada para estes propósitos.

En canto a como evoluciona a participación do alumnado de ECE-L nas prácticas de modelización ao longo da etapa, os resultados indican que participaron nun número crecente de tipos de prácticas de modelización, como uso, construción e avaliación de modelos. Durante os tres anos da etapa, incrementou a súa solvencia no uso e construción de modelos en diferentes modos semióticos, como físico, xestual e visual. No primeiro ano precisaban de apoio da mestra para interpretar representacións, mentres que no terceiro ano interpretábanas de xeito autónomo. Ademais, de maneira espontánea, no terceiro ano iniciaron discusións sobre como podía ser representado un concepto ou fenómeno cun debuxo, e viceversa, mentres que no primeiro ano este tipo de discusións eran fomentadas pola mestra. Desde o primeiro ano de educación infantil usaron representacións que contiñan elementos simbólicos e icónicos; e produciron representacións nas que incluíron ambos tipos de elementos, propostos pola mestra. A medida que foron avanzando na etapa, foron adquirindo unha maior autonomía na produción de representacións. No terceiro ano foron capaces de incorporar elementos simbólicos e suxerirllos aos seus compañeiros, ademais de desenvolver códigos propios, por exemplo códigos de cor.

En relación ao terceiro obxectivo de investigación, caracterizamos a evolución das explicacións sobre cambios de estado do alumnado de terceiro de educación infantil. Antes de participar no proxecto escolar, as ennas e nenos de ECE3-L era capaz de identificar compoñentes, procesos e relacionar os fenómenos de cambios de estado coa temperatura. Despois de participar no proxecto, foron capaces de propoñer como tiñan lugar estes fenómenos e de explicalos facendo uso de vocabulario científico e de modelos. As explicacións sobre evaporación e condensación evolucionaron de forma diferente. O alumnado recoñeceu o fenómeno de evaporación nunha maior variedade de contextos que o fenómeno de condensación. O alumnado identificou que a evaporación implicaba un cambio de estado, mentres que describiu a condensación como gotas que "se pegan".

As explicacións do alumnado emerxen da interacción entre o coñecemento cotián e o coñecemento científico escolar (da aula). Por exemplo, relacionaron as súas observacións de condensación nos experimentos coa presenza de bafo á hora do baño. Ademais, foron capaces de aplicar o concepto científico do cambio de líquido a gas para explicar as súas experiencias cotiás, como a aparición de bafo nun plástico ao botarlle o alento nun día frío: "¡Se evaporó! El agua del aliento".

En canto ao cuarto obxectivo de investigación, identificáronse as estratexias docentes das mestras de ECE-L e ECE3-P que apoian a participación do alumnado nas prácticas científicas. A implementación na aula de proxectos de ciencia de longa duración permitiu tratar un número reducido contidos en gran profundidade. Isto posibilitou a recorrencia e a reflexión sobre os mesmos, e sobre as observación e experimentos e o seu significado. Nestas aulas, o tempo dedicado a discutir as observacións e os experimentos foi maior que o tempo que se dedicou a levalos a cabo. As mestras fomentaron a discusión sobre como e porque sabemos o que sabemos. O recoñecemento do alumnado de educación infantil como produtor válido de coñecemento, a valoración as súas aportacións aos proxectos e o fomento da súa autonomía no discurso, promoveron a participación do alumnado nas prácticas científicas de maneira sofisticada.

Implicacións Educativas

A continuación destacamos algunas das implicacións educativas derivadas dos resultados do estudo.

Suxerimos a pertinencia de incluir a *observación cun propósito* nas aulas de educación infantil, pero tamén de primaria e niveles superiores, xa que favorece a participación do alumnado nas prácticas científicas, ao tratarse dunha práctica que pode complementar outras, como deseñar investigacións, pero que tal vez suscite menos dificultades para o alumnado de menor idade. Os datos xerados mediante observación cun propósito poden ser usados para a revisión de ideas. Dado que a capacidade de avaliar as propias ideas é imprescindible para unha aprendizaxe autónoma, é importante fornecer ao alumnado de oportunidades para revisar as súas teorías desde os primeiros anos de escolarización.

Suxerimos a implementación proxectos de ciencia de longa duración na aula de educación infantil. Para apoiar a participación do alumnado nas prácticas científicas de maneiras complexas, os proxectos deberían deseñarse de maneira que inclúan tempo para discutir e reflexionar sobre as experiencias, sobre como e porque se xerou coñecemento; e é recomendable que impliquen a participación do alumnado en diferentes prácticas de modelización, como o uso, a produción e a avaliación de modelos, nunha variedade de modos semióticos.

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