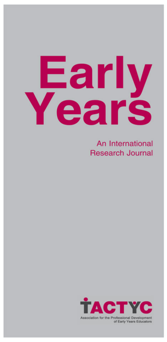

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From inception to implementation: an Argentine case study of teachers enacting early years inquiry-based science

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ABSTRACT
This study aimed to understand the process of implementing an early years inquiry-based science unit, focusing on the challenges teachers faced. A two-month professional development programme was implemented in two preschool classrooms. Two teachers with no inquiry-based science experience were provided with structured curriculum units and weekly pedagogical coach. Teachers observed coach-led model lessons (which were filmed and used during subsequent training) before implementing four 30-min lessons. Lessons and teacher interviews post-programme were filmed and their verbatim transcriptions analysed. Overall, teachers executed most basic elements from the units, providing students with opportunities to engage in scientific explorations. However, they struggled to use the activities for the collective construction of knowledge and development of scientific skills. Analysis of student–teacher dialogues shows that teachers rarely used student inputs to articulate prior knowledge with new concepts or to inform teaching, sometimes constructing misleading ideas about the nature of science as a result.

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Science education; early years; teacher training; structured curriculum unit; coaching

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Introduction

Whether to enrich early childhood education or to contribute to student readiness, there is an extended and growing consensus that science teaching can and should begin in early years (Eshach and Fried 2005). Preschool presents great opportunities to nourish student curiosity, and effective science teaching in early schooling can lay the foundations of rigorous thinking and understandings about the nature of science (Akerson et al. 2011). Importantly, studies have shown correlations between achievements in kindergarten and success in academic and personal trajectories (Melhuish 2011; Schweinhart and Weikart 1997). An effective early science education has also been associated with improved outcomes in later educational stages (Kumtepe, Kaya, and Kumtepe 2009).

However, although many countries teach science at the preschool level and teachers acknowledge the value of learning science (Spektor-Levy, Baruch, and Mevarech 2013), research has shown that students are given very limited opportunities to learn science in

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the early years (Saçkes 2014). In order to explain this, various studies have analysed teachers' perceptions and have found that teachers refer to time constraints, lack of materials and their need to prioritize other subject areas such as literacy or numeracy (Olgan 2015). Also, studies have suggested that teachers do not feel confident teaching science topics because they lack content knowledge and a clear representation of what inquiry-based science teaching looks like in the classrooms of early year students (Kallery 2004).

In Argentina, the context of this study, national standards for early years (compulsory level at ages 4 and 5) promote science teaching from an inquiry-based perspective framed in the knowledge of the social and natural environment subject area (Argentine Ministry of Education, Science and Technology 2004). However, as it the case with other countries, science is rarely prioritised or seen in early years classrooms (Batiuk and Coria 2015), and early years teachers' professional development (PD) opportunities are often focused on more general pedagogical aspects such as play, rather than on science (INFoD 2017).

Furthermore, schools in disadvantaged areas of much of Latin America, including Argentina, tend to deliver lower quality education than those in more privileged contexts (Office of Educational Evaluation 2016). They often have less experienced and less well prepared teachers and their students obtain lower results in all subject areas in national examinations, both at elementary and secondary school levels (Argentine Ministry of Education and Sports 2016; OECD 2016). Although there are no national data for early years education specifically, such inequalities could be presumed to be structural across the entire education system.

One way of improving the quality of education is through the professional development (PD) of teachers. In Argentina, a widespread PD strategy is the provision of structured curriculum units (Argentine Ministry of Education and Sports 2016; Davis et al. 2014), supplemented at times by pedagogical coaches, who guide teachers in the organisation, content and pedagogy of a given topic, hence providing concrete ways of implementing changes in teaching practices (Kraft and Blazar 2016). Structured curriculum units work from the idea that supplying teachers with standardised, prescriptive classroom materials and instructions can support teachers in improving their practice. In early years, as in science, studies have shown how such interventions can improve student outcomes (Wright and Gotwals 2017) and teachers' confidence (Neuman, Pinkham, and Kaefer 2015; Saçkes 2014). However, there is considerable debate on the extent to which supplying these curriculum documents is effective in teachers' professional development (Bassi, Meghir, and Reynoso 2016). Critical voices point out the limitations of using PD packages to improve teaching quality, adducing that they might undermine teacher agency under a 'delivery' model (Dadds 1997).

Moreover, research in early years science education has highlighted gaps between the proposed and implemented curriculum that might cause concern (Kallery and Psillos 2002). Even when using structured curriculum units, science teachers' adaptation of these materials often results in a lowering of the cognitive load, making lessons easier and more aligned to their regular practice (Davis, Janssen, and Van Driel 2016). This could be due to teachers' personal schooling trajectories, beliefs about science, difficulties with the science content or their personal starting points related to their teaching experience (Arias et al. 2016; Forbes and Davis 2010).

In this sense, although many features of effective PD programmes are known (Darling-Hammond et al. 2009), there is a need to better understand how to help early years practitioners to bridge the gap between the proposed and enacted curriculum (Sheridan et al.

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2009), particularly in science. Unpacking the processes teachers go through when implementing and appropriating inquiry-based science curriculum units in early years classrooms may help design more effective teacher-training models for this specific and important area.

In this study, we aim to understand better which aspects of inquiry-based science units can be readily integrated into low socio-economic status classrooms by teachers with limited science teaching experience, and which other aspects need further support. We were interested in understanding where gaps in implementation occurred, and how such gaps affect the learning opportunities available for students.

To do so, we explored the implementation of two inquiry-based science curriculum units in two early years classrooms in a low socio-economic area following a teacher PD programme. We analysed video recordings from two classrooms (one class of four-year-olds, hereafter referred to as K4, and one class of five-year-olds, hereafter K5), where teachers were provided with structured curriculum units and support from a pedagogical coach on a weekly basis for two months. Coaching consisted of discussing the activities proposed by the structured curriculum (including the revision of the scientific concepts and a particular focus on the use of questions), watching the coach model the unit in real classrooms, followed by analysis of the coach's lessons (using filmed videos of her lessons). Neither teacher was experienced in inquiry-based science pedagogies, so we were interested in seeing which elements of the unit were readily implemented, and which elements proved more challenging. In particular, we analysed the dialogues promoted between teachers and students to evaluate how teachers' modes of implementation impacted on opportunities for meaningful learning from a constructivist perspective. Throughout, our research questions were:

(1) How do teachers implement an early years inquiry-based science unit following an intensive PD programme? What elements of the unit were implemented as conceived and which presented greater challenges for teachers?
(2) How do gaps in implementation affect the learning opportunities for students?

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Methodology

School context and teachers' background

Two teachers were chosen to participate in this study. Both worked at a small state-subsidised school and family support centre in an underprivileged parish in the province of Buenos Aires. They were chosen as they were each in charge of both K4 and K5 classrooms, the obligatory year groups in Argentina. This preschool provides half-day provision, with a morning and an afternoon shift made up of different groups of children, meaning that each teacher has two classes. Both teachers had a degree in early years teaching with over ten years of experience in their position, although neither had taught science through inquiry-based methods before. Both teachers lived in the local community.

The school was selected as it was the institution which best reflected a typical state-subsidised school (in terms of socio-economic context and resources) from those which had previously partnered with the university for various local educational projects. Ongoing PD opportunities available at the school were limited. The school had a tradition of focusing on students' emotional and physical well-being, as well as social support for their families (rather than focusing on academic school readiness). School leaders were very supportive of the

PD programme, facilitating the implementation in every possible way, as well as participating in several training sessions and observing the model lessons.

PD science programme

Both teachers participated in an *in situ* two-month intensive professional development programme. The programme followed the theoretical perspective of inquiry-based science teaching. Based on a constructivist paradigm and aligned with national curriculum guidelines, the inquiry-based approach enhances the active engagement of students in investigations of everyday phenomena while participating in the collective construction of meaning (Harlen 2000).

The PD programme consisted of three main parts, each underpinned by weekly coaching sessions: (i) Observation of coach-implemented model lessons, (ii) Understanding the structured curriculum unit and (iii) Implementation and feedback.

Observation of coach-implemented model lessons

All lessons from the units were first modelled by the coach during the afternoon shift of the participating teachers' school (following training; both teachers taught the same lesson with a different group of children during the morning shift). Teachers observed all four lessons from their corresponding units. Watching the coach teach the unit to their own students was meant as an important part of the training, since it provided teachers with a 'proof of possibility' (Cochran-Smith 2004) (i.e. demonstrating that teaching inquiry-based science was possible in the teachers' own context). Also, all lessons were filmed and given to the teachers.

Using these filmed lessons served two purposes. First, videos were used during weekly coaching sessions as a tool for planning and reflection. Secondly, it provided teachers with a chance to revisit and review elements of the model lessons in their own time whilst looking at the structured curriculum document.

Understanding the structured curriculum unit

Each teacher received a structured curriculum document outlining a 4-week inquiry-based science unit. Each unit included four science lessons that promoted the development of age-appropriate skills (Argentine Ministry of Education, Science and Technology 2004; Okyay 2016) (see Table 1 for an outline of the units – the complete structured curriculum documents can be downloaded in Spanish at http://educacion.udesa.edu.ar/ciencias/inspiradoras/).

Following an inquiry-based science theoretical rationale, all lessons explicitly outlined elements of effective early years science practice, mainly through the use of hands-on activities with small groups and with sense-making discussions (Kamii 2014). Through the collective exploration of enriched contexts, children are expected to put into play investigative skills such as formulating questions and hypotheses, making observations and drawing conclusions into play (Furman 2016). In doing so, children are encouraged to constantly express their ideas, verbalise their observations and communicate with others, which teachers need to mediate for the collective construction of knowledge (Benlloch 1992).

The unit included several activities that aimed to foment meaningful teacher–student dialogues. In addition, the structured curriculum documents included recommendations addressed to teachers regarding specific aspects of inquiry-based science teaching and their

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Table 1. Outline of the structured curriculum unit objectives and activities.

Lesson objectives		Activities and comments
Panel A: K4 Unit – Light and Shadows		
Lesson 1	**I spy with my little eye: What do we need to be able to see?**	*Opening: Light Explorers*
		Experiment: The dark room and Mystery boxes
	We use our eyes to see To see, we also need light	Closing: What did we learn?
Lesson 2	**Why can I see through some materials but not through others?**	Opening: Toys go Hide and Seek Experiment: Using transparent, translucent and opaque lenses
	Different materials let light pass through, or not (transparent, translucent and opaque)	*Closing: Choosing the right materials*
Lesson 3	**What are shadows and how are they made?**	Opening: Where's my shadow?
	Objects block light to make shadows	Experiment: Changing the shape of my shadow
	Shadows have the same shape as the object that made them	Closing: Shadows in the playground
Lesson 4	**Can shadows change size?**	Opening: Find the missing shadow
	The size of a shadow depends on the distance between the light source, the object and the surface on which the shadow is formed	Experiment: Big shadow, small shadow Closing: What did we learn?
Panel B: K5 Unit – Sound		
Lesson 1	**What sounds surround us?**	Opening: Sound detectives
	We are surrounded by sounds We use our ears to listen	Experiment: Making sounds with our bodies and identifying mystery sounds
	Silence is the absence of sound	Closing: What did we learn?
Lesson 2	**Are all sounds the same?**	Opening: Comparing Loud/Soft and High/Low sounds
	Sounds can be loud or softSounds can be high-pitched or low-pitched	*Experiment: The water bottle xylophone*
		Closing: What did we learn?
Lesson 3	**What does sound travel through?**	*Opening: Where does sound travel through?*
	Sounds travels to reach our ears	Experiment: Making sound travel through solids and liquids
	Sound can travel through different materials (solids, liquids and gases)	Closing: Drawing what we learnt
Lesson 4	**Sound Detectives in action!**	Opening: Can a sound be Loud and High?
	Our school is full of different types of sound that we can hear with our ears and identify	Experiment: Sound Detectives investigate the school Closing: Identifying combined sounds
Panel C: Science skills for both units (Nature of Science)		
Across all four lessons	Observe and describe natural phenomena	
	Compare between different situations, looking for similarities and differences	
	Develop hypotheses, predict possible outcomes and test their ideas	
	Record and share observations through writing and drawings	
	Interpret observations and data collected	
	Communicate findings and learning to others	

Note: Highlighted activities in italics are those analysed in the findings section.

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rationale. For example, the units emphasised the importance of including specific terminology only when the students had understood the main ideas under study through explorations and specific activities, rather than as starting points.

Implementation and feedback

Teachers then implemented the lessons in their classrooms, which were observed by the coach and also filmed. One-on-one weekly coaching sessions then covered all elements of inquiry-based science, grounded specifically within the activities outlined in the unit and briefly providing teachers with the theoretical rationale underpinning each activity. Sessions lasted between one and two hours, bringing the total intervention (including observation of model classes, weekly sessions, observation and feedback sessions, and 'homework') to roughly 30 h.

Each session involved watching videos of the model lesson, which was in turn used as a tool for reflection (in terms of 'What went well in that lesson?' 'Where the objectives met?' 'What could have been improved?'). This was watched in parallel with the structured curriculum unit, where coach and teacher went over the specific structure, rationale and learning objectives of each proposed activity. This space also provided an opportunity for the coach to go over any content-specific queries as they arose. Teachers also had direct communication with the coach via cell phone messaging, which they frequently took advantage of to consult on specific aspects of the units' implementation. This allowed teachers to form a close connection with the coach, allowing for immediate responses to specific queries. Due to the nature of cell phone messaging, this limited the exchange to specific, small-scale questions.

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Data collection and analysis

In order to capture in depth the complexity of the implementation process of the units, we conducted a qualitative study (Denzin and Lincoln 2005) that included thematic analysis of lesson transcripts and inquiry into teachers' perceptions.

First, all eight lessons, each one lasting approximately 30 min, across both year groups were filmed and transcribed verbatim. Filming allowed us to capture the different interactions (such as whole group, small group and teacher–student dialogues) occurring in the classroom and transcribe them in detail given our interest in make meaning of the interventions in their context. Taking into account recommendations made by Stigler et al. (1999) regarding filming lessons, filmmakers with experience in documenting classroom instruction were hired and several lessons prior to those involved in this study were filmed to allow children to become accustomed to the filming process.

A thematic analysis of participant teacher lessons was undertaken (Boyatzis 1998), mining the data for predefined themes. These themes included several 'general pedagogy' aspects such as effective lesson openers, checking for understanding, questioning and plenaries, as well as key features of effective inquiry-based science such as investigating students' prior understanding, implementation of science experiments and facilitating meaningful observations to guide students to conclusions. The selection of such themes was consistent with aspects that were particularly addressed by the structured curriculum and during the PD sessions.

We compared the lessons' transcripts with both the written curriculum and coach-led implementation to identify gaps in implementation, by matching what actually was said and done in a real classroom with the 'ideal' proposed curriculum as had been conceived. Several illustrative fragments were selected and analysed throughout our findings (see italics in Table 1). Fragments have been organised to mirror the order in which they might occur in a lesson, i.e. beginning with opening starters, followed by experimental activities and finishing with closing sessions.

Secondly, we were interested in inquiring into teachers' perceptions, for they can provide further insight on teaching practice (Tsai 2002). For this purpose, at the end of the unit, teachers were interviewed for approximately 20 min using a semi-structured format regarding their perceptions and experience of working with the structured curriculum and coach. Teachers were asked to describe their overall experiences of the PD programme, as well as the strengths and challenges they associated with working in this way and what results they saw in terms of student learning and motivation. We analysed the interviews in relation to our main findings from the lesson transcripts.

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Findings

There were several green lights on the road from inception to implementation, but also roadblocks and potholes.

When answering our first research question we found that both teachers showed similar successes and challenges when implementing the science lessons. They were able to execute most of the basic elements of the proposed activities, providing students with opportunities to engage in scientific explorations. They performed the sequence of suggested activities, connecting them to everyday phenomena, tightening ties with the students' experiences and engaging children in concrete exploration activities through the use of various resources. Given that neither of the teachers was experienced in teaching science on a regular basis before (neither having used an inquiry-based approach), this represented an important step forward in the teachers' practice.

However, when comparing the implemented versus the proposed curriculum, we found that teachers encountered challenges in guiding students towards many of the units' learning goals, such as making accurate observations, formulating relevant hypotheses and linking their observations with scientific concepts and ideas. That is, teachers struggled to take full advantage of the activities as devices for the collective construction of knowledge and the development of scientific skills. Moreover, in some cases teacher interventions were contrary to the spirit of the units, resulting in counterproductive student learning to the extent that they strengthened content misconceptions and constructed misleading ideas about the nature of science.

Looking closer at the student–teacher dialogues reveals gaps on the path from inception to implementation. Below we discuss in depth the main challenges encountered by the teachers, exemplifying the difficulties encountered at each stage of a typical early years science lesson.

Starting lessons by building on students' prior knowledge towards lesson goals

One aspect of the unit implementation that teachers struggled with was how to articulate students' prior knowledge with new concepts. This became evident, for example, in class openings.

In this study, both units started with a 'thought shower' led by teacher-based questions such as: 'What do you think a Sound Detective could do?' (K5) and 'What do you think a Light Explorer does?' (K4). The aim in both cases (as explicitly expressed in the units) was to guide students to identify that detectives and explorers observe, search for answers, solve problems, investigate objects and discover things they don't know, just like scientists. However, when responding to students' answers, teachers struggled to focus on the importance of developing certain inquiry-based skills, and rather allowed class discussions to revolve around ideas not relevant to the goals of the lessons, as Fragment 1 illustrates. Here, the teacher is reminding students of their previous science lessons, and going over the idea that explorers use certain skills to help them reach new knowledge.

Fragment 1. Opening of Lesson 3 'Light explorers', Unit on Light and Shadows (K4).

Teacher: Do you remember what we were?

Student: Explorers!

Teacher: We were explorers. What do explorers do?

Student: Explore.

Student: They walked slowly.

Teacher: They walked slowly.

Student: They learned.

Teacher: Yes they learned.

Student: They used magnifying glasses.

Teacher: When we were Explorers, what did the Explorers do?

Student: Walk slowly.

Teacher: They walked slowly.

Student: They look with their eyes.

Teacher: Look slowly.

Student: Snakes walk slowly.

Teacher: Snakes walk slowly.

Student: Yeah! They don't walk, they just move like that!

Student: Investigate dinosaurs!

Teacher: They move. They investigate dinosaurs, yes.

Despite the teacher posing a relevant question to open the discussion (e.g. 'What do explorers do?'), this fragment shows that she struggled to build knowledge based on student answers from a constructivist perspective. Even when students gave answers that were on the right track towards identifying skills (such as 'they learned' or 'look with their eyes'), the teacher did not use these answers to take the conversation in the proposed direction – for instance, prompting students to remember what and how they had learned and observed in previous lessons. Instead, the teacher validated students' answers by repeating them, even when they were not relevant to the goals she was pursuing (e.g. 'Snakes walk slowly').

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Given that this was the opening moment of the lesson, this may have started the rest of the lesson off on weak foundations. As the fragment suggests, teacher–student dialogues generated confusion and missed the opportunities to build on students' prior knowledge to construct more complex ideas later on.

Using scientific explorations to promote understanding

Another key component of the inquiry-based science unit was the implementation of exploration activities as a means to guide the learning of scientific concepts and skills. However, although teachers were able to conduct the 'hands-on' aspect of the exploratory activities, they encountered difficulties when using them to promote student understanding.

For example, one activity from the K5 unit encouraged students to play a xylophone with the aim of identifying that different bars produce sounds of different pitch and understand that the pitch of the sound depends on the length of the bar played (shorter bars produce high-pitch sounds and longer bars produce low-pitch sounds). As Fragment 2 shows, the teacher struggled to connect physical explorations and taking up student responses to build on the lesson learning objectives.

Fragment 2. Exploration activity 'The water bottle xylophone', Lesson 2, Unit on Sound (K5).

Teacher: You say this sound, is what? [*She played the shortest bar on the xylophone, expecting students to identify the sound as* 'high-pitched']

Some students: Loud.

Other students: Soft.

Teacher: And this one? [*She played the longest bar, which produces a low-pitched sound*]

Some students: Loud.

Other students: Loud and strong.

Teacher: Why do you think that is?

Student: Because one is bigger than the other.

Teacher: Or shor …? [*Expecting her students to say* 'shorter']

Student: Because this one is bigger and this one is smaller and this one is even smaller.

Teacher: Or what? Shor …

Student: Shorter.

Teacher: Do you know what these sounds are called?

Student: Cow sounds?

Teacher: No!

Student: Chicken sounds?

Teacher: High-pitched and low-pitched. Which one was high-pitched?

Student: The big ones.

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Teacher: The big ones?

Student: The short ones.

As we can see, although the teacher replicated the activity mostly as described – using the xylophone to learn about high- and low-pitched sounds – when student answers diverged from those she expected (such as when they responded 'loud/soft', referring to volume, instead of 'high/low-pitch' which is what she was asking about), she was unable to effectively take these responses on board to redirect her teaching. In this case, differing answers remained unresolved (such as when some students said 'loud' and others 'soft' – both responses were ignored). This is consistent with studies that show teachers may find correcting children's misconceptions to meet particular learning goals challenging (Sewell 2002). In this sense, despite the fact that the teacher managed to promote active participation by the students by asking questions, we consider this 'false participation' in that student answers did not then guide the lesson's development.

A basic feature of inquiry-based activities is that they allow for a variety of unexpected (and possibly mistaken) student responses that teachers then need to manage. Interestingly, a very similar situation arose when the coach modelled the lesson beforehand (i.e. students giving contradictory answers to questions based on the pitch and length of xylophone keys). In this case, differing student responses were used to justify further explorations and explanations based on observations, as seen in Fragment 3.

Fragment 3. Coach implementation of Exploration activity '*The water bottle xylophone*', Lesson 2, Unit on Sound (K5).

Coach: Does the short bar make a high or low sound?

Student: Low-pitched

Student: High

Coach: Let's see, let's try, let's try again. [*Plays the short bar*] Is it high or low?

Student: High.

Coach: High. So if I want to make a high-pitched sound, do I play the short bar or the long bar?

Student: Short bar.

In this case, unlike the K5 teacher, the coach's interventions strengthened the link between student observations and the conclusions drawn from them. However, despite teachers observing firsthand (and then watching the video in subsequent training), these coach-led, concrete and similar examples of how to manage unexpected student responses were insufficient for teachers to then take the approach back to their own classrooms.

Moreover, even though the concepts required in this case were basic, we noticed that teachers had difficulties on multiple occasions when responding to student inputs (particularly if they were incorrect). One reason why teachers may have struggled with the responses was a lack of experience with the scientific content (Garbett 2003; Kallery and Psillos 2001). Despite going over the content during training, our analysis shows that teachers were unable to use the content in a flexible manner, and occasionally committed factual errors (for example, at one point the K5 teacher asked a student to make a higher pitched noise by kicking the ground harder, and the K4 teacher avoided the explanation that linked shadow size to the distance of the light source). Teachers themselves also identified that they were unfamiliar

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with the science content during interviews. For example, the K5 teacher expressed: 'These were topics that I, personally, had never seen nor would have worked on. The units helped us go over these new science themes in a different way' (K5 teacher – Post PD interview).

Emphasising understanding over terminology throughout lessons

Another aspect of implementation which proved challenging was the teachers' tendency to focus on specific terminology ('saying the right word'), rather than promoting a deeper conceptual understanding. Although vocabulary development is important in early years, during the PD programme teachers had been instructed to first focus on teaching concepts and ideas, and introducing new terminology later, rather than the other way around. This follows an inquiry-based science rationale, in which students answer authentic questions rather than demonstrate already known and named concepts (Furman and Podestá 2010). In fact, the structured curriculum unit explicitly stated: 'It is recommended to first retrieve the terms that children genuinely use (e.g. "sharp" when meaning "high-pitched") and *then* explain the terminology more accurately'.

This proved challenging to the teachers. As an example, in Fragment 2 there was a moment when a student suggested that one bar was 'bigger' than another, and that this might influence how the nature of a sound changes. Although not 100% accurate, this answer is however well-directed, and could have been used to guide students towards understanding that longer bars make lower pitched sounds. However, instead of stretching this answer, for example by asking which bar they are referring to when they say 'it is bigger', the K5 teacher gave strong clues trying to get students to say the specific word she had in mind (e.g. 'Or shor ...?' when seeking students to reply 'shorter'). This type of verbal cloze questioning (Chin 2006) can be useful to elicit keywords, particularly for students who are not articulate or not verbally expressive, but we feel in this case that it removed the focus away from meaningful observation.

When compared with the coach's lessons we see a different strategy in action; in the face of incomplete or imprecise responses from the students, the coach paraphrased their ideas to guide students towards new knowledge. For example, during the same activity she established the following dialogue to help students understand how pitch and bar length are related:

Fragment 4. Coach implementation of exploration activity 'The water bottle xylophone', Lesson 2, Unit on Sound (K5).

Coach: Why do they sound different, are the bars the same?

Student: No, because look – this one is high, this is more or less, this is smaller, this is medium, this is more or less big [*student pointing to different keys*]

Coach: So he says it's different because the bars are all different, there are some big ones and some little ones.

Contrary to the previous cases, this short dialogue values students' contributions without an over-reliance on the specific 'short/long' vocabulary. This acceptance of the way students naturally express themselves, before helping them to refine and re-express their findings with more accurate language, is a key role for early years teachers (Benlloch 1992) (hence also addressed in the units). In this sense, both teachers seemed to be fairly far from this target and less able to flexibly adapt their own explanations to the starting points of their

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students. Again, seeing the coach in action and reflecting upon this lesson during sessions was insufficient in terms of promoting similar teaching practices during implementation.

Promoting reasoning over guesswork during experiments

Following the overemphasis on terminology, teachers also formulated questions that created dialogues that further promoted guesswork rather than reasoning based on observations.

For instance, teachers recurrently asked 'why?' in a premature manner, such as when students did not have the theoretical knowledge to answer accurately (such as '*why* are sounds high pitched or loud?' – a correct answer would involve sound wavelengths and frequencies, which far exceeds K5 knowledge). Other guess-based questions such as 'how high-pitched will that be?' were asked when the students had no way of knowing the answer. This goes in the opposite direction to the activity and could reinforce misleading understanding of the nature of science, appealing to guessing instead of deductive reasoning. In these cases, other questions such as 'how are the sounds different?' or 'how did you realize?' would have been more effective in appealing to reasoning, rather than simply guessing and then shouting out.

A consequence of this lack of progression and connection between the students' observations and their reasoning can be seen in Fragment 2 when the teacher asked to identify types of sounds (based on loud/soft and high/low pitch – concepts they had been studying in the previous lessons), and students responded with names of animal sounds, potentially showing a lack of connection between the activities and learning taking place. In this sense, the science lessons did not encourage students to make sense of the world around them, but rather introduced an 'anything goes' aspect to responding to teachers' questions.

Organising learning systematically to draw conclusions

The final aspect of science teaching highlighted by the units was the importance of including plenaries and moments of reflection at the end of each lesson or activity, as a way of monitoring the comprehension and learning of students. These moments give students a chance to organise their learning systematically. In order to do this, different strategies were proposed, such as the use of evaluation questions, the incorporation of drawing 'what we learnt today' and other evaluation activities, for example, resolving problematic situations or discussing solutions to mysteries or challenges intended to use what they had learnt.

Although both teachers did implement these plenaries, organising students to sit in a circle or carry out the activities (such as drawing the experiments they had conducted), again we found that this was done only on a very superficial and basic level. Teachers had difficulty using these activities to assess student progress, also because of the difficulty found with effective questioning (as discussed previously). As an example, Fragment 5 shows how the K4 teacher finished a section of the unit by presenting students with challenges designed to evaluate students' understanding of transparent, translucent and opaque materials (in this case, suggesting different materials for building parts of a house, linking the properties of materials to their use).

Fragment 5. Closing activity '*Choosing the right materials*', Lesson 2, Unit on Light and Shadows (K4).

Teacher: They are finishing my house and a man came, a builder who's finishing my house. And you know what the builder asked me?

Student: What?

Teacher: He said: I have to do the bathroom door and the kitchen door. He asked me: What material do I need for the bathroom door?

Student: Materials.

Teacher: But what material did he need?

Student: Toilet paper for the bathroom.

Teacher: Obviously. And you know what the builder asked? He asked: What do I do with the bathroom door? Can I make it transparent, a transparent material, or do I put an opaque material in it?

Student: Opaque.

Teacher: And if I make it transparent what happens to the door?

Student: It's transparent.

Student: The light can come through.

Teacher: But what if I pee? What'll be wrong with the door?

Student: Nothing.

Teacher: Can you see if I make it transparent?

Student: No.

Student: Yes.

Teacher: Can you see me when I go and pee?

Students: No! (*laughing*)

Teacher: What if I make it opaque?

Student: No.

In this case, the teacher is again struggling to ask the right questions to encourage students to fully reason and then demonstrate their understanding of how a material's properties (such as being transparent) can influence its use (such as being used for a window or door). As the fragment shows, when the teacher asks: 'What material do I need for a bathroom door?' she does not make the connection between the properties of materials previously studied. It was also noticeable that the activities that had been completed in class beforehand were never mentioned, and perhaps this is why students went back to their prior knowledge in their answers (such as when shouting out 'toilet paper' rather than a material they had studied). In the same way, when she asked 'can you see me when I go pee?' students replied 'No!' in a humorous and embarrassed manner, suggesting once again that they are not linking their answers to reflections based on the lesson, but rather on prior ideas.

'Choosing the right materials for the door' problem was conceived as an evaluative opportunity where the teacher could get students to use their new knowledge of different materials in new situations. Instead, as the fragment shows, this activity highlighted student confusions around the topic being assessed (and may have even generated more confusion).

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Similar cases of 'underusing' closing activities were seen across various lessons involving both teachers. In terms of student learning, this proves to be ineffective in both allowing teachers to assess student understanding and thus reorient their teaching to help them progress in their learning, and in helping students to organise and apply their knowledge to new situations.

Discussion and conclusions

Our study aimed to understand how two teachers from a preschool serving a low socio-economic status context implemented an inquiry-based science unit following an intensive PD programme. In particular, we aimed to understand which aspects of the unit were implemented 'as proposed', and which proved more challenging to translate and integrate effectively in the classroom. With regard to these challenges, we sought to understand how this gap in implementation affected students' learning opportunities.

The first major finding was that, following a two-month intervention, teachers were able to start adopting the basic aspects of inquiry-based science approaches, particularly those that were 'by the book'. Classes were taught sequentially, largely following the outlines given by the structured curriculum units, teaching the topics in more depth as opposed to one-off 'experiments'. What is interesting is that, superficially, the lessons implemented by the teachers all seemed successful – there was plenty of evidence of children completing the experiments, engaging with questions and conversing about science.

However, upon a closer look, when analysing the actual conversations that took place during lessons, we find that much of this seemingly successful implementation was not actually true to the constructivist spirit of the teaching unit. Much of what students shouted out seemed to be guessed, rather than reasoned – which may lead to an incorrect understanding of the nature of science (trying to guess what the teacher wants to hear, rather than actually reasoning and justifying their views based on evidence from observations). In this sense, we found that teachers struggled to truly 'use' the activities as opportunities to learn new content; rather they were things to 'do' when teaching science. We feel that this shows a loss in terms of learning opportunities, as students are not being given full opportunities to practice meaningful observations and draw reasoned conclusions that would lead to meaning-making.

This was evidenced particularly strongly when analysing classroom conversations when unexpected 'off the script' moments happened – such as students giving incorrect answers, disagreeing or guessing randomly. This was when the true 'implementation gap' could be seen when compared to the coach-modelled lessons – both teachers struggled to adequately listen and respond to the real learning presented by their students, instead rushing through the activities as planned without actually taking into account where their students were learning conceptually.

Various difficulties arose, particularly, when having to 'improvise' questions (i.e. use questions other than those explicitly outlined in the sequence). Both teachers intensively asked questions throughout their lessons. However, as our findings illustrate, in general these questions did not help students to progress in their understanding of scientific ideas. In this sense, we agree with Newton (2013, 6) who argues that 'half a dozen, well-posed questions that focus on particular thinking needs at crucial times are likely to be of more benefit than a hundred questions, scattered like confetti and demanding only the quick recall of facts'.

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Good questioning involves effective questions as part of a back and forth exchange between students and teachers, where teachers use students' replies to assess and inform the future directions of their teachings and in turn guide students towards more profound and cumulative understandings (Aizikovitch-Udi, Clarke, and Star 2013). It also requires of teachers a deep understanding of the intimate relationship between thought and language (Baquero 1996). Our study shows how effective questioning was an enormous challenge for our participant teachers. Providing base questions in a unit, and modelling their use in teachers' own classrooms was still not enough (at least within a two month intervention timeframe) to help teachers who were unfamiliar with inquiry-based practices to adopt these techniques confidently, especially during activities which foment unexpected student responses. We found that both teachers encountered difficulties in picking up on the students' answers to help them draw conclusions from their experiences and systematise knowledge, particularly when they gave erroneous or unconvincing answers. In this regard, our analysis shows teachers' lack of several important competencies identified by Andersson and Gullberg (2014) namely, paying attention to and using children's previous experiences, capturing unexpected student inputs, asking challenging and stimulating questions and listening to the children and their explanations.

That teachers struggled with questioning their students and engaging in meaningful dialogues may point to a larger gap in their understanding of how students learn science, and especially of the role of language in meaning-making (Lemke 1990). Our findings suggest the need to include the analysis of actual student–teacher conversations, including those reflected on from their own filmed lessons, as a central part of PD efforts. This would allow teachers to practise and subsequently reflect on which questions work best to promote student understanding, and examine effective and ineffective ways to pick up student responses (especially incorrect ones) (Lemov, Woolway, and Yezzi 2012).

As others have shown, another, different challenge found was the actual science content (Kallery and Psillos 2001): both teachers were unable to truly master the content within the time frame of the programme. Although the scientific concepts involved in the unit were relatively basic, the teachers showed their lack of confidence in these concepts both through their dialogues with students, and later in their interviews. Given the simplicity of the scientific concepts for early years students, it could be naively assumed that professional development efforts do not need to devote much time to the detailed explanation of those concepts. However, in this case our findings do not support this assumption.

Our findings also show that teachers also struggled with the development of students' scientific skills. Despite this, both teachers expressed satisfaction with the outcomes of their lessons and valued how inquiry-based approaches had been useful to help students understand 'how science is done'. During the interviews teachers mentioned how students 'formed hypotheses' or 'came to conclusions'. However, our more focused analysis shows that students only did this at a superficial level (as we mentioned, often being asked to guess and not having their answers followed up and linked to actual observations). In this sense, we see a large gap between the 'discourse level' of teacher practice, and the 'classroom level' of teacher lesson implementation. This may point to teachers' misunderstandings regarding the nature of science (Akerson, Buzzelli, and Donnelly 2010), with science conceived as a linear method of hypothesis testing as opposed to a more social and collaborative meaning-making endeavour based on the exploration of natural phenomena.

Despite the small-scale nature of this study, we believe it adds valuable insights to the existing literature for early years science professional development. In particular, our study shows that although certain elements of inquiry-based science pedagogy are readily incorporated by teachers (such as engaging students in explorations of natural phenomena), others (such as using student–teacher dialogues to advance student science learning, reflecting on the nature of science or mastering science content) may be more challenging and, thus, need to be an important part of PD programmes. This, we believe, is particularly necessary in school contexts where children experience disadvantage and where paving the road from inception to implementation is most urgent and may have profound effects on children's life chances.

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