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The Role of Intermediary Objects of Learning in Early Years Chemistry and Physics

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Abstract
The overall aim of the present study is to study model-based teaching and the collaborative inquiry learning of chemical processes and physical phenomena in preschool, with a specific focus on the verbal communication established between teachers and children (4–5 years old). According to variation theory, learning is always directed at a specific content, called the object of learning. This study aims at highlighting what 'threatens' the teacher's and preschool children's intersubjectivity during the teaching of chemistry and physics content, and at discussing possible ways to continue the teaching of an object of learning, once sufficient intersubjectivity in a teaching/learning situation has been lost. The result shows the need for the teacher to divide and split a larger object of learning, such as water purification, into smaller learning steps 'on the way' in order to hinder breaks in intersubjectivity that otherwise may arise. We introduce the notion of 'overarching object of learning' and 'intermediary object of learning', and the intermediary objects of learning identified in this study are categorized as belonging to three different themes: the role of words, the role of theoretical models and science concepts, and the role of analogies and abstractions. The teacher's awareness of intermediary objects of learning as critical aspects for children's individual learning is crucial for the teaching of everyday science in a preschool setting.

Keywords Preschool · Pre-service teacher education · Early years chemistry and physics

Introduction

This article describes an analysis of teaching instances that are part of a 3-year in-service preschool teacher programme. The overall aim of the in-service project is—together with preschool teachers—to develop, implement and analyse science teaching based on a team-negotiated, consensus theoretical science model, and the collaborative inquiry learning of chemical processes and physical phenomena in preschool. The involved work teams (140 preschool teachers in total), supported by the authors, developed and implemented research-based activities following the theoretical framework described below. In this study, our interest is directed towards the verbal communication established between teachers and children during teaching implemented in a subset of five work teams from the involved preschools. The 3-year in-service programme is ongoing and the teaching instances reported here took place during the first year.

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Background

Preschool is part of the Swedish educational system as a voluntary form of school for children aged 1–5 years. Municipalities are obliged to provide a place in a preschool for all children and the composition of students normally reflects the local community concerning socio-economic class and ethnicity. The cost of preschool is nationally subsidised, and according to national statistics, 84% of 1–5 year-olds participate in preschools (Swedish National Agency for Education 2017). Preschool teachers (3.5 years university studies) are responsible for pedagogical activities enabling children to play, create, explore, and learn.

In 1998, a national curriculum for preschool introduced different content areas to cover. One of these areas was science. At that time, there was a strong emphasis on environmental issues, nature and outdoor experiences, which always has had its place in Swedish preschools (cf. Thulin 2011). This first national curriculum mirrored this tradition in emphasizing the importance of a caring attitude towards the environment. In connection to the revision of the national curriculum in 2010, the definition of science was broadened and the 'science-goal' was formulated as:

> "The preschool should strive to ensure that each child develop their understanding of science and relationships in nature, as well as knowledge of plants, animals, and also simple chemical processes and physical phenomena". (Swedish National Agency for Education 2011 p. 10).

The renewed curriculum introduced in 2011 set in motion discussions about the goals for science in preschools, as well as the resulting consequences for pre- and in-service preschool teacher's education (Sundberg and Ottander 2013; Andersson and Gullberg 2014; Roychoudhury 2014; Thulin and Redfors 2017). The Swedish preschool is goal-directed, which indicates a need of 'early childhood education didactics' (Fleer and Pramling 2015; Larsson 2013; Fridberg et al. 2017), with teachers developing knowledge of both the content in focus, and ways to provide favourable conditions for children's learning (Fleer 2009; Spektor-Levy et al. 2013; Thulin and Redfors 2017). As argued "The challenge goes beyond content knowledge to teacher beliefs and pedagogy practices" (Fleer 2009, p. 1074). The pedagogical task for Swedish preschool has continued to be reinforced, and in 2019 the current national curriculum (Swedish National Agency for Education 2019) was introduced.

The focus of the 3-year in-service preschool teacher programme is on developing the teaching of science, with a specific focus on simple chemical processes and physical phenomena. The intention and strength of science is to describe and predict real phenomena by organizing explanations through theories and theoretical models. In the scientific research process, empirical and theoretical work are intertwined leading to (re)construction of theories and theoretical models. The formation of these is an interactive process of discussions, experiments and observations made within the science community. From a science-studies perspective, it is known that different emphases are possible on how these processes could be described (Erduran and Dagher 2014). This 3-year in-service preschool teacher programme uses a semantic view of theoretical models (Koponen 2007; Adúriz-Bravo 2012; and references therein to: van Fraassen 1980; Giere 1997; Suppe 2000; Develaki 2007), where theoretical models are viewed to form families or classes linking theories with experiments and practices, and where the focus is on the explanatory powers of the theoretical models. The relation between a theoretical model and real world phenomena is in many ways complex, and observations and experiments are by necessity embedded in theory, and are therefore, 'theory laden' (Hanson 1958), see Fig. 1.

In trying to bridge the often-disconnected worlds of theory and educational practice, this 3-year in-service project methodology is based on design-based research (Barab and Squire 2004). The iterative and participatory philosophy of design-based research can foster the development of sustainable, empirically tested practices. Teaching activities have been jointly developed in design-groups consisting of a team of preschool teachers and a researcher. The design work has been focused on bridging everyday experiences and science to everyday questions concerning chemistry and physics, e.g., energy use, water usage and purification, and light production. With this arrangement, we strive to inspire the preschool teachers to appreciate the relevance of choosing science activities connected to the everyday lives of children.

As stated above, the 3-year in-service programme focuses on model-based inquiry teaching and has introduced variation theory (Marton and Booth 1997; Marton 2015) as a framework for teaching. One of the basic ideas of variation theory (Marton and Booth 1997) is that learning is always directed at specific content, such as a phenomenon, object, skill, or aspect of reality. This is called the object of learning (OL) and 'learning' entails a qualitative change in the way of experiencing the object of learning—ways of acting originate from ways of experiencing (Marton et al. 2004).

To experience an object of learning requires that the learner becomes aware of its different aspects, and is provided an opportunity to discern these aspects simultaneously. Aspects that are critical for the intended way of experiencing the object of learning for a given learner are called critical aspects. An object has many aspects, and

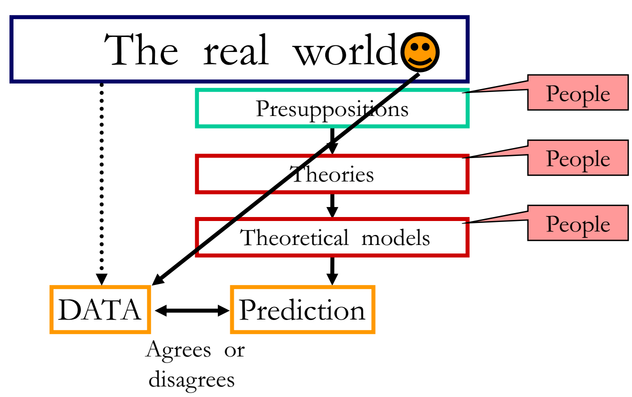

Fig. 1 Observation of real world objects and events is viewed as theory laden. Predictions, and observations made by a person in order to obtain data are seen as "filtered" by theoretical models generated from established frameworks. Adapted from Redfors (2016)

not all aspects are critical for all learners. Learners in all ages need to be given opportunity to experience aspects that are critical for them and their abilities. For every object of learning, and for every learner, there are critical aspects that the learners must be able to discern (Marton and Booth 1997; Marton 2015).

The object of learning is dynamic in nature. The *intended object of learning* planned by the teacher is staged in the form of the *enacted object of learning*, referring to how the teacher implements and enables experiences of the object of learning in teaching situations. Furthermore, the intended object of learning is experienced by the learners in the enacted teaching/learning situation, but as a consequence, what the learners actually experience is the *lived object of learning,* which again is different, and may vary among the involved learners (Marton et al. 2004).

Marton (2015) argues that we must learn to discern every quality (feature), innate or not. Awareness of a single feature cannot exist without the awareness of differences (variation) between features. Contrast helps the learner to discern a particular phenomenon, concept, or aspect, and differentiate it from other phenomena, concepts, or aspects. When a child can contrast blue with red, a dimension of variation of colours will open up, with blue as a value along this dimension of variation. Contrasting blue with what is "not blue" (e.g., red, yellow, green) allows critical aspects of blue to be separated out. Learners can then learn from sameness by looking at different blue colours (e.g., light blue, navy, or indigo), and aspects that vary within blue can be discerned. By paying attention to what remains unchanged in the background of varying appearances, the learner can generalize to an invariant principle or aspect. For example, the defining aspects that constitute the colour blue.

The object of learning for teaching implemented during this 3-year in-service preschool teacher programme would be constituted of a theoretical explanatory model (Fig. 1), established with consensus within a design group (preschool teachers and researcher). This would normally mean that the two domains of science discussed by Eshach (2006) for children's science learning; content (concepts and explanatory models) and investigations (hypothesis, problematizing, questions and experiments) would be intertwined with ideas of the nature of science. The teaching would strive to encompass children's ideas about science as an object of learning by meta-reflective dialogues, in communicating the purpose, the what and how perspective, and the learner's own role in relation to the experienced science content (e.g., Pramling Samuelsson and Asplund Carlsson 2008). However, the two domains of science are planned to be made visible in the analysis by separating them out as direct (domain 1) and indirect objects of learning (domain 2).

Theoretical Framework

Intersubjectivity

In this study, our interest is directed towards the verbal communication established between teachers and children during teaching implementations in a subset of five work teams involved in a 3-year in-service programme. Being able to interact with someone and sharing attention to a particular content focus can be seen as a fundamental aspect of teaching (Doverborg et al. 2013). However, a shared attention towards something is not enough for learning. Rather, the participants also have to establish an agreement in the dialogue about sharing perspectives and being engaged in the same activity. This kind of acting can be named intersubjectivity, described by Stern (2004) as an ability to share experiences and feelings with another person. According to Rommetveit (1974), intersubjectivity during communication should be seen as an ongoing process rather than a state, where participants seek to establish enough joint understanding, temporarily sufficient to keep communication or an activity going. In an earlier report (Fridberg et al. 2019), verbal communication between teachers and children in science learning situations in preschool were analysed for intersubjectivity. That study focused on excerpts representing qualitative differences in intersubjectivity during teacher–child and child-child communication, related to the object of learning. Two qualitatively different ways to describe varieties of intersubjectivity were found; sufficient and illusory intersubjectivity (Rommetveit 1974; Ivarsson 2003; Fridberg et al. 2019). Sufficient intersubjectivity entails a communication with mutual and simultaneous understanding between the teacher and the child/children. This means that the teacher at the same time considers what children recognize *and* the intended object of learning, aiming to establish a relationship between the two in order to challenge and expand children's previous experiences (Thulin 2011). Illusory intersubjectivity is, in contrast to sufficient intersubjectivity, arises in situations where the teacher is under the impression that s/he and the children have agreed on how to understand the communication taking place during the teaching/learning activities involving an object of learning. Our analysis showed how the teacher and children seemingly talked about the same thing, but put different meanings to everyday words, or missed out on each other's intentions due to not expressing it specifically enough, explicitly naming objects and concepts, i.e., using a decontextualized language. For example, words such as 'it' instead of 'the water' markedly hindered the intersubjective communication of different aspects of the activities. Based on this previous study (Fridberg et al.

2019), we here further analyse excerpts of communication during the teaching of various science phenomena with a focus on aspects of the object of learning.

Intended Object of Learning

Variation theory (Marton and Booth 1997; Marton 2015) is used as a framework for the 3-year in-service programme and the intended and enacted aspects of the teaching and learning activities. The formulation of an object of learning leads to discussion about critical aspects, contrast, and what 'learning' to plan and strive for means, as a teacher. This was discussed in the design-groups during the formulation of the intended object of learning and planned activities, i.e., the teaching. A specific object of learning has been formulated for the planned sequence of activities by each of the design-groups. In order to analyse the enacted object of learning, the sequences were implemented and the enacted teaching was video-recorded. Critical aspects for the children's experiencing of the object of learning were formulated, together with strategies of how to deploy features of contrast that could help clarify the critical aspects. The critical aspects should vary against a constant background. Contrast can be achieved if something varies and something else is held constant.

Furthermore, each of the design groups discussed and defined markers for children, having experienced the object of learning by formulating answers to questions like: What knowledge do we want the children to develop? What does it mean to understand this? What varies between different ways of understanding this? How do the children understand it when we start? How do we want them to understand it afterwards? How do we want them to use acquired knowledge afterwards? These questions guided the design groups in their planning of a formulated object of learning.

Aim and Research Question

The overall aim of the 3-year in-service project is to develop, implement, and study science teaching based on a consensus theoretical science model and collaborative inquiry learning of chemical processes and physical phenomena. This study of five work teams participating in the 3-year in-service preschool teacher programme aims specifically to highlight features 'threatening' the teacher's and preschool children's intersubjectivity during the teaching of integrated chemistry and physics content. Furthermore, it aims at discussing possible ways to continue the teaching of an object of learning, once sufficient intersubjectivity in a teaching/learning situation has been lost. The study is guided by the research questions:

- What possible explanations are there for occurrences of insufficient intersubjective communication during enactment of science objects of learning?
- What possible ways are there for the teaching to continue fruitfully once intersubjectivity has been lost?

Sample and Data Collection

The investigated work groups in the preschools, the age of the children, and respective object of learning are described in Table 1. In total, fifteen activities were observed. Each activity was 20–50 min long and involved teachers and children working with the chosen scientific phenomenon. The preschools are multicultural and children come from different socio-economic and ethnic backgrounds; most children do not have Swedish as their first language. We video-recorded children and teachers enacting the activity.

Analysis

The analysis of the videos focused on children's and teachers' communication. The videos were transcribed and communication and interactions during the activities have been analysed with a focus on affordances made by the teachers and the ways in which children create meaning through the established communication. In this first step of analysis, agreement was reached on how to define intersubjectivity in the communication, following the theoretical framework (Rommetveit 1974; Ivarsson 2003). Intersubjectivity as an analytical tool refers to communication where the teacher and children seek to share perspectives, not only attention, when addressing aspects of the object of learning. The communication then appear coordinated enough to keep the

Table 1 Involved preschools, group of children, and respective objects of learning (OL)

Preschool	Years of age	Number of children	Object of learning	Comment
Preschool I	3	5	Water purification	Purification through different filters
Preschool II	5	4	Water purification	Purification through different filters
Preschool III	4–5	6	Water purification	Illustration of a sewage system
Preschool IV	3–5	5	Water usage	Illustration of cost and amount of water
Preschool V	4–5	7	Wind force	Creation of a miniature wind mill

object of learning in focus, either verbally, or non-verbally by bodily expressions like pointing, or nodding. In the previous study (Fridberg et al. 2019) excerpts showing intersubjectivity in relation to the object of learning of 8–20 turns, where the communication was interpreted to have intersubjectivity related to the object of learning, had been identified. By 'turns' we mean participants responding to each other by verbal and sometimes non-verbal expressions. From this set of excerpts, situations representing breaks in intersubjectivity were identified through a double-blind procedure of two of the authors and excerpts before, during and after these 'breaks' where collected, discussed and selected for further analysis. The in-depth qualitative analysis of the excerpts was then carried out by a thematic procedure by two researchers. In this process, categories of qualitatively different ways for insufficient intersubjectivity to be instigated emerged—often connected to what we have come to call 'intermediary objects of learning'. A discussion among all four researchers established the final categories.

Results

Our findings will be discussed below in relation to the three science phenomena related to chemistry and physics that were focused on in the teaching activities in the five preschools. In four of the preschools, different aspects of water was the chosen theme due to children´s previous work with, and experience of, water. Three of the groups worked with water purification and the fourth group with water usage and costs, as the object of learning. In the fifth group, the children had shown interest for a windmill installation outside the preschool. Thus, the chosen physics phenomenon, and object of learning, was wind force.

During the analysis of the video-recorded enacted object of learning, an interesting pattern emerged. When a break in intersubjectivity around an object of learning (e.g., wind force or water purification) was identified, this break pointed to the need of a certain 'step on the way' towards the object of learning being addressed. Our interpretation is that without the teacher's awareness of this necessary teaching step, there is a risk of the children not being guided, or having their attention directed, towards the critical aspects they need to ascertain in order to learn about the object of learning. For the children to continue on their journey to learn about the intended, or *overarching* object of learning, *intermediary* objects of learning appeared as necessary 'stepping stones'. We have therefore introduced the notion of an 'overarching object of learning' and 'intermediary object of learning'. We use the excerpts below, with examples of breaks in intersubjectivity, to exemplify the concept of the latter. The intermediary objects of learning are categorized as belonging to the following three different categories:

- *the role of words*

  representing the use of everyday words

- *the role of theoretical models and science concepts*

  representing the use of science concepts and model constituents

- *the role of analogies and abstractions*

  representing situations where abstract thinking is needed.

The Role of Words

A recurrent theme when intersubjectivity is broken between teacher and children can be found in misunderstandings of words or terms used by the teacher. In the following example from preschool I, the teacher and children have set up a plastic bottle (1.5 l) for purification of dirty water. The bottle has been cut in half and the upper part placed upside down in the lower part, as a funnel. The water is filtered through stones into the bottle and the following discussion takes place:

Example 1: Water purification as the overarching object of learning

Teacher	[*Holds the bottle where the dirty water has been filtered through the stones. The water is of the same brown colour as before. The bottle's upper part with the stones are still left in the bottle's lower part, containing the water]* Was the water cleaned?
Children	Yes!
Teacher	Is it clean? [*The teacher lifts the pitcher with water left in it and holds it next to the bottle with the stones/filtered water*]
Children	Yes
Arne	But it? brown
Teacher	Is it brown? Is the water clean if it's brown?
Nero	Yes!
Teacher	Is it?
Nero	Yes, look there! [*Points to the stones in the bottle*]
Teacher	Yes but look here. [*Puts the pitcher down but continues to hold the bottle with the stones/filtered water and points to the lower part with the water*]

Teacher	The water has been pouring through here [*shows through the stones*], through the stones. [*All children follow with interest*]
Arne	Through the stones
Teacher	What do you think Farah? Is it clean? [*Holds up the bottle with the stones/filtered water*]
Farah	Yes

The broken intersubjectivity occurs because of the word 'clean'. It appears that in the teacher's mind, this word refers to the water in the plastic bottle she holds it up and shows the children; the aim and overarching object of learning being that the children should learn that water may be purified more or less efficiently. In Nero's mind however, and according to his previous experience and knowledge, it seems as if water is something used for *cleaning something else*, such as the stones. The notion that it is the actual water that will be more or less cleaned in the experiment seems to have eluded him. According to Eshach (2006), different aspects of science can be viewed as belonging to one of two domains: domain 1—concepts and explanatory models, or domain 2—scientific work processes in terms of investigations, with hypothesis, problematizing, questions and experiments. We consider the word 'clean' to be part of domain 1, a crucial concept to understand for the described teaching/learning situation to be fruitful. The word 'clean' can also be seen as an intermediary object of learning on the way to the overarching object of learning, that water can be purified in different ways. If the teacher and children instead were to discuss and explore the verb 'to clean' from different angles, this could result in sufficient intersubjectivity when they later continue their inquiry of water purification.

The Role of Theoretical Models and Science Concepts

In preschool V, the teacher and children worked with wind force as their natural science phenomenon. The teacher had in earlier activities expressed the terms air, propeller, and speed as important concepts. On a previous occasion, they had built a miniature windmill and watched the propeller spin when they used a fan or blew at it. The propeller spinning resulted in a small lamp on the windmill starting to shine. In the following excerpt, the teacher and children recapture the event and what was needed for the lamp to be lit:

Example 2: Wind force as the overarching object of learning

Teacher 1	Right or left (gesturing), but how this windmill works (grabs the windmill)… Air was needed, you all thought it was needed for the lamp down there to start to shine.
Teacher 2	Air was needed but then it needed to spin, right? (Shows in the air)
Mario	When it's night, why does it blow in the night, then?
Teacher 1	It also blows during night time, yes.

Mario raises the interesting question 'why does it blow in the night?'. It is not clarified what he means by this statement but his prior experiences seems to be in conflict with wind blowing during night time. His following remark shows how he continues trying to understand the relation between sunshine and wind:

Teacher 1	The big windmills, we have pictures over there (points)
Teacher 2	Yes, (gets up and walk towards the pictures) but what are those for?
Mario	I think it's those that want a little air here, I think if it's sunny, than it doesn't blow, but when it's wind, then they spin!

The above examples indicate the wind, its relation to the sun and light, and where the wind originates from, as intermediary objects of learning, are worth taking time to explore on the way towards the overarching object of learning, which has to do with the wind force.

In example 3 below, the children and the teacher have collected water from a nearby creek. The main object of learning expressed by the teacher is for the children to have the opportunity to learn different ways to purify 'dirty' water by using varying materials. To accomplish this the teacher used plastic bottles as wastewater-treatment plants, with different filters of varying permeability. As in example 1, the plastic bottles were cut in half and the upper part of each bottle placed upside-down in its lower part so that the upper part constituted a funnel. The funnels were thereafter filled with stones, coals and a coffee filter, respectively. Here, it is the word 'difference' that hinders the intersubjectivity:

Example 3: Water purification as the overarching object of learning

Teacher	Mm, but between those two, do you see any difference there? [Two plastic bottles]
Amar	It's not the same
Teacher	What differs then?
Amar	It's not the same colour
Teacher	No? What differs then?
Amar	This and this [grabs one of the bottles]
Teacher	Mm, but what is that like then?

Amar	On this, there is a lot of difference and this [the other bottle] is small
Teacher	What's the difference you mean?
Amar	That one is small difference and that one is lots of difference

In light of Eshach's (2006) definition of domain 1 and domain 2, 'difference' could be viewed not only as a word, but also as a concept, and the comparative feature of a scientific work process, which is a necessary part of inquiry teaching. Fleer et al. (2014) show that with a 'sciencing attitude', teachers have unique possibilities to teach science in preschool. By exploring and discussing findings, children learn critical thinking and how to discuss hypotheses. Important features in observing and exploring includes noting and comparing patterns, in order to see what *differs* in different outcomes. A possibility for the teacher in the present example could be to continue the teaching by intermediary steps by directing the children's attention towards large and small differences, and/or by letting the children compare the bottles and describe what is alike and what is not alike in them.

Also apparent from the different water purification activities is that the notion of a 'filter' would need to be addressed, as an intermediary object of learning. None of the teachers explained the general concept of a filter and the reason for stones, coal, gravel or a coffee filter being used in the activities. The discussions involved what worked best for purification (e.g. the stones or the coffee filter), but the actual point of using different filters *with different pore sizes* is left unaddressed. Below are two excerpts from a situation in preschool II, with circumstances as described in the preceding example, where the children were supposed to compare and describe the difference in how water looks, after being purified in different ways:

Example 4: Water purification as the overarching object of learning

Teacher	But now today I thought that when we should go on, that we should see if we can pour the water through other… other like that… other material than just gravel. So I will take… Let's see here
	…
Teacher	You may choose here. We must use all (points to funnels and filters) so someone must have kind of… so that not everyone has the same

Here, instead of using the word 'filter', the teacher speaks of 'other material'. The meaning of the word 'material' is broader than that for 'filter', the latter involving the process of something being filtered. The verb 'to filtrate' could be viewed as part of domain 2 (Eshach 2006) with its content oriented towards different aspects of the scientific work process. To deepen explorations around 'to filtrate' could be an intermediary object of learning on the way towards the overarching object of learning: water purification. Furthermore, the example illustrates the use of a local, contextualised language when the teacher leaves out the word 'filter', or 'material', in the second statement. We have previously shown the importance of the teacher finding ways to support the creation of links between the children's perspectives, the use of local (contextualized) language and a more exact (de-contextualized) language, including scientific language belonging to the object of learning, and the consensus theoretical science model. The teacher needs to pay conscientious attention to the use of language when working with children towards an object of learning, otherwise risking illusory intersubjectivity (Fridberg et al. 2019).

The Role of Analogies and Abstractions

When teaching about scientific phenomena teachers use different models, representations or abstractions, to explain the involved concepts. These abstractions could be verbal metaphors, or something more practical in nature. In the example below, the teacher in preschool III wants to illustrate a sewage system to show how water used at home on a daily basis is collected in larger sewers to eventually be purified. The teacher uses a large glass jar in which water with different substances, representing waste from water in the bathroom or the kitchen, etc. poured. When the teacher and children pour representative samples of toothpaste, food waste, etc. into the jar, it quickly fills up. As shown in Example 5, Oscar pays attention to this:

Example 5: Water purification as the overarching object of learning

Teacher	Then perhaps mom does the dishes (pours washing-up liquid into the jar). Then maybe mom washes some clothes (pours washing powder into the jar). If we use the sink then maybe… maybe we eat dinner. Cannot drink the juice…
Oscar	Soon it will overflood…
Teacher	Now we go to the toilet again… Then we have a spa at home with mom and maybe remove make-up… or dad
Oscar	We need to flush
Oscar	I think we have to stop flushing now!

In Example 5, a break in intersubjectivity can be seen around the chosen representation of a sewage system. First, all waste, whether from the kitchen sink or bathroom sink or the toilet, goes into the same 'sink' in the form of the glass jar. It may not be evident for the children that the jar could be said to represent a sewer at the end of several connections of sewage pipes from different sinks. Also, Oscar talks about the need to flush which indicates that he interprets the jar to be a toilet. Second, unlike a real sewage system, the glass jar can be full of waste with the risk of water overflowing, a feature noticed by the student. This creates an obstacle in the model that does not exist in real life and Oscar focuses his attention on this obstacle when saying 'I think we have to stop flushing now!'.

Creating the dirty water in the glass jar may be viewed as an intermediary step towards the overarching object of learning, which is water purification. However, the complexity of the model situation initiates experiences among the children, Oscar especially, that appears to hinder the continuation of the water-purification activity. The teacher continues the activity by creating a purification system of a plastic bottle, similar to that explained in Example 1. The dirty water from the jar is poured onto the filter constituted of stones. In the ongoing discussion, not shown here, the children still focus on overflowing and whether this may happen in the plastic bottle. Hence, when an observation by a child is not acknowledged, it lingers and impedes focus further on. This is something that can be detected during detailed analysis of enacted teaching, but is difficult to handle in the teaching situation.

In the next Example, from preschool IV, the object of learning according to the teacher is for the children to notice how much water they use at home and how much the usage costs. The children have had 'homework' and taken pictures in their homes of situations where they use water, and the parents have helped their children to estimate how much water they use during a day. In Example 6, the teacher and children have compared and illustrated the children's different water usage by stacking small wooden blocks on the floor. The teacher continues the activity by using Swedish kronas and a litre measure:

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Example 6: Water usage as the overarching object of learning

Teacher	This much water that Erik and Maria use each day, that was about 60–70 of these big here. That was a lot (shows the litre measure) every day
Erik	Nods
Teacher	(Shows a Swedish krona) Do you know? Do you know what kind of money this is?
Alma	Yes new one-krona
Teacher	This is one krona. How much is this then? (Holds up two one-kronas)
Alma	Two kronas
Teacher	Yes and 70 L is about this much each day. So Maria uses about this many each day and Erik uses this many each day on water. Do you think it feels like a lot?
Children	Hm

In the teaching situation Example 6 is taken from, the children meet several abstractions, such as Swedish kronas, litre measures, and wooden blocks, representing their water usage and cost. The teacher is ambitious in the enactment of the chosen object of learning but with the risk of introducing too many abstractions at a time to the children, who need to be able to transform between real water and the different representations used by the teacher. The overarching object of learning involves two different aspects of water, usage and cost of the usage. Accordingly, the overarching object of learning would need to be divided into at least two intermediary objects of learning, in order for the children to be able to experience the critical aspects of the object of learning, and connect this to future actions in their everyday lives.

Discussion

In this study we have analysed what causes sufficient intersubjectivity in communication to break during the teaching and learning of a science phenomenon, and pointed to the teacher's use of words, abstractions and science concepts in the process. Our analysis shows how misunderstandings and uncertainties may arise around any of these areas, hindering the children's possibility to discern critical aspects for their learning. This links directly to what has been reported earlier, that teachers need to be aware of what the children are expected to pay attention to during teaching, the intended object of learning, and what they are actually occupied with, the child's perspective (Pramling Samuelsson and Asplund Carlsson 2008). Meanwhile, they must also 'remain' in the situation, listen, and ask stimulating questions (Andersson and Gullberg 2014).

We have previously seen the importance of teachers holding a double focus involving both children's perspectives and the object of learning (Fridberg et al. 2019). However, there is also the need to be prepared for pitfalls and stumble blocks in terms of intermediary objects of learning and the use of de-contextualised language. All of this would be reflected in children's possibilities to learn. As argued by Fleer (2009, p. 1074), "The challenge goes beyond content knowledge to teacher beliefs and pedagogy practices", but the teaching process is also related to content knowledge in the work team. We have described this above in terms of the need for consensus about a theoretical explanatory model constituting the basis of teaching towards an object of learning, which has also been advocated in earlier studies (Larsson 2013; Spektor-Levy et al. 2013).

Interestingly, our examples of breaks in intersubjectivity, and hence, the obscuring of critical aspects, also point to a solution in terms of what we refer to as intermediary objects of learning. In each break identified, a 'stepping stone' that needs to be addressed on the way to the overarching object of learning could be found. This is in accordance with earlier work on the importance of considering the learners' prior experiences (Eshach 2006; Helldén 2005; Pramling Samuelsson and Asplund Carlsson 2008). In the present study, this could be exemplified by Mario wondering about whether wind blows at night (example 2). In order to help Mario with his understanding, the teacher needs to consider his prior experience and turn it into an intermediary object of learning, focusing on wind, sunshine, and the day-and-night cycle as separate phenomena. Another example in the material is the teacher's need to focus the children's understanding of the verb 'to clean', before continuing her teaching of water purification. The significance of verbs when working with young children and science is highlighted by Areljung (2016). She describes how thinking of science phenomena in terms of verbs instead of, as traditionally, nouns, inspired preschool teachers to think of science in a new way. The everyday character of familiar words like floating, melting, rolling, etc., helped the teachers to identify chemical processes and physical phenomena and potentially to make way for children's ownership of their investigations (Areljung 2016). We agree with this child-centred approach to science teaching and extend the discussion by describing verbs, such as 'to clean' as potential intermediary objects of learning, and in the investigated context, important for children's learning.

The process of filtering dirty wastewater is of course not visible to the children. The 'dirt' in the water is constituted by small particles—ones not visible to the human eye. Hence, the children cannot 'see' the filtering and experience the active part of a filter. The theoretical model of matter as constituted by particles is (as all theoretical models) a human construction (cf. Adúriz-Bravo 2012) and not 'visible', which is also discussed by Hansson et al. (2015) where physics teaching is analysed in terms of the relations made between theoretical models and reality. However, the 'particle model' is the basis of the agreed upon consensus science model, and can be built upon by teachers in the teaching about filters by communicating about invisible 'dirt particles'. For examples of fruitful implementations of teaching based on the 'particle model', see for instance Löfgren (2009) for a longitudinal study that uses the particular nature of matter in the teaching of science. A subtle introduction of particle models would probably help the children both in understanding the investigated science processes, and in generating building blocks for future encounters with science and theoretical models.

In the examples above about the model of the drain, and the problems the limitations of the physical model involves for the communication between teacher and children, the difference between the enacted and lived object of learning is indicated. The enacted teaching is focusing on what goes into the physical model of a drain and how the water becomes contaminated. The children are observing the actions, but experience the process based on their prior experiences. Hence, focusing on parts of the process is important to them. This brings in the well-known pitfalls of analogies and metaphors (Duit 1991) and the could-be potential of trying to use self-generated analogies in teaching (viz. Wong 1993; Haglund 2013). In previous research, the importance of the learners' experiences of both the target and source domains of a metaphor or an analogy has been exemplified. In this case, it means that the abstractions needed for understanding the usage of the physical model implicates a shared experience/understanding of the source domain, i.e., the different sinks and drains in a house. However, this seemed to be problematic in the investigated situation.

Conclusion and Implications

In summary, the result of this study points to misunderstandings of words, science concepts, and abstractions as important factors involved when a break in intersubjectivity occurs between teacher and children during work with a science phenomenon.

However, during this project we have also discussed the importance of preschool teacher work groups in formulating and agreeing upon consensus explanatory models (Fig. 1) of investigated phenomenon. The entire model, is after that formulated as the object of learning, with the teaching planned to offer affordances that make it possible for the children to experience critical aspects of the objects of learning. Even though the explanatory models are deemed suitable for young children, they sometimes are experienced as quite complicated. In several instances, as exemplified above, there appeared intermediary objects of learning—features the children needed to experience on the way to embracing the intended object of learning. Examples of these learning objects include:

- Water purification, i.e., water is purifiable and can be made 'clean' and drinkable

    That water in itself can be "dirty" and not always something to use for cleaning other items
    That there are different experiences of the concept 'clean'
    That the 'dirt' in dirty water consists of particles of different sizes, ranging from easily observed particles

to very small indistinguishable ones that can make the water opaque

That dirty water can be ‘cleaned’ by filtering through filters of different kinds

That dirt particles of different sizes are ‘caught’ in filters differently, depending on the size of the ‘holes’ in the filter

That filters with very small holes makes the water stream very slow, and purification plants therefore start with filtering the bigger particles with coarse filters

That there are tiny, unobservable microorganisms (bacteria) that also need to be removed before the water is drinkable

- Wind force accelerating a propeller, i.e., the movement of molecules in the air transfers energy to the propellers of the wind mills, making them rotate, which makes a generator spin and produce electricity

That there is air also inside a room, which can be used to produce ‘wind’

That windmills have several crucial components

That moving air equals wind and can be produced with a fan or by blowing through ones mouth

That air particles (molecules) collide with the blades of the propeller, which start to move because they are set at an angle

That the propeller’s spinning makes the generator spin, which in turn generates electricity

The analysis reported here indicates that sometimes the intermediary objects of learning were anticipated, but sometimes they were not, and in the latter case were only identified in hindsight during the analysis of the enacted teaching. That indicates that preschool teachers in work groups could benefit from having time to discuss the intended teaching and bring in different perspectives, in order to be able to pinpoint potential intermediary objects of learning.

This study also highlights the importance of teachers creating opportunities for children to experience critical aspects of the object of learning, with a focus on variation. For example, in the teaching of water purification, teachers might vary filter materials and scaffold the children so they can experience the behaviour of filters with differing sizes of ‘holes’. Another example encountered was when the variation of the amount and speed of the air led to ‘a collision’ with the propeller of the windmill. For these variations to be discerned, they need to be related to the critical aspects for every involved child. They need to be connected to the children’s prior experiences. A strong point for the investigated teaching is the connection to the everyday lives of the children. However, in order to bring this to its full potential, all the critical aspects for all the involved children need to be realized. Otherwise, some of them will get side tracked and focus on unintended aspects and occurrences.

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