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“I call it frost”: Features of scientific social language during inquiry-based learning on the particulate nature of matter

Abstract

The particulate nature of matter (PNM) is central to learning science and is a difficult concept for both children and adults. The purpose of this study is to examine how teaching materials from an integrated science and literacy curriculum on the PNM affects communication between pre-service teachers. We were especially interested in examining communication during an activity phase and whether and how participants used PNM models. The interactions between participants were recorded with headcams and analysed using a framework developed by Mortimer and Scott in 2003. The findings revealed that the participants mainly described what they observed directly using scientific words and concepts, but they did not necessarily use PNM models or theoretical knowledge spontaneously. Research indicates that the ability to use knowledge at a theoretical level is key to understanding chemical concepts, so our study underscores the importance of explicitly asking participants to use models and theoretical knowledge.

INTRODUCTION

The particulate nature of matter (PNM) is a central concept necessary for understanding several fundamental topics in science (Tsaparlis & Sevian, 2013). Despite its importance in school curricula, studies have revealed students' difficulties in understanding the PNM (Harrison & Treagust, 2002; Özmen, Ayas, & Coştu, 2002). Some studies have reported that many pre-service teachers (PSTs) have an insufficient understanding of the PNM (e.g., Håland, 2010; Valanides, 2000), which may undermine the comprehension of the PNM in future student generations (Yip, 1998). Studies have indicated that inquiry-based approaches enhance understanding by providing rich opportunities for reflection and talk (Cervetti, Barber, Dorph, Pearson, & Goldsmith, 2012), so such methods may enhance PST education on the PNM.

According to Minner, Levy and Century (2009), the term “inquiry-based” refers to students learning by thinking about and experimenting with a phenomenon or problem, often mirroring the processes used by scientists. Inquiry-based approaches are often based on students working in small groups. To study how students communicate in such situations, we examined the features of student-student communication for insight into the type of understanding being constructed. Understanding phase transitions relies on understanding sub-microscopic particles. A study by Chittleborough and Treagust (2007) indicated that students’ understanding of chemical concepts is influenced by their abilities to use and interpret chemical models. According to Mortimer and Scott (2003), a theoretical level of knowledge draws on theoretical entities that are not observable in phenomena themselves. Communication between pre-service science teachers during an inquiry-based activity was therefore analysed to explore how students used models of PNM and a theoretical level of knowledge.

FRAMEWORKS AND CONCEPTS

Talking to learn science

According to a sociocultural perspective, one meets new ideas in social situations (Vygotsky, 1986). Ideas are rehearsed between people drawing on a range of communication modes, such as talk. There is a transition from social to individual planes, where interlocutors make individual meaning of what is being communicated. From this perspective, language is one of the most important resources for mediating learning.

From a sociocultural standpoint, learning science involves learning the social language of the scientific community (Scott, Asoko & Leach, 2007). The term “social language” was first defined by Bakhtin (1981) as “a discourse peculiar to a specific stratum of society within a given system at a given time”. Science education researchers Leach and Scott (2002) argued that scientific knowledge itself can be portrayed as a social language. From a sociocultural perspective, learning science therefore involves being initiated into scientific ways of knowing and to the concepts and models of conventional science (Driver, Asoko, Leach, Mortimer, Scott, 1994).

This is also consistent with research indicating that to learn science, students must learn to use the language of science (Lemke, 1990; Wellington & Osborne, 2001). Results from an experimental programme for talk and reasoning indicated that talk-based activities can have a useful function in scaffolding the development of reasoning and scientific understanding (Mercer, Dawes, Wegerif & Sams, 2004). Other studies have indicated that science learning is most effective when students can combine first-hand experiences with opportunities for reflection and rich talk (Cervetti et al., 2012). For instance, in their study of 94 fourth-grade classes, Cervetti et al. (2012) found that students of teachers who used an integrated science and literacy approach had greater gains in science understanding, science vocabulary and science writing than other students. Furthermore, in an in-depth study of two elementary school teachers, Haug and Ødegaard (2014) proposed that students’ levels of word knowledge develop into conceptual knowledge when students are required to apply key concepts in their talk throughout all phases of inquiry.

The way students communicate during a science lesson is important for their learning outcomes and abilities to make meaning of the scientific story being told (Mortimer & Scott, 2003). To study how talk is involved in meaning-making in science classrooms, Mortimer and Scott (2003) developed an analytical framework for scientific social language based on the sociocultural view of teaching and learning.

They elaborated the content of classroom interactions used by either teacher or students into three fundamental features of scientific social language: description, explanation and generalisation (see Figure 1 and Table 1). These features can be further qualified as empirical or theoretical. According to Mortimer and Scott (2003, p. 31), descriptions and explanations are characterised as empirical when they are based on directly observable properties. In contrast, *those that draw upon entities created*

through the theoretical discourse of science, as in the case of microscopic particle models, are characterised as theoretical.

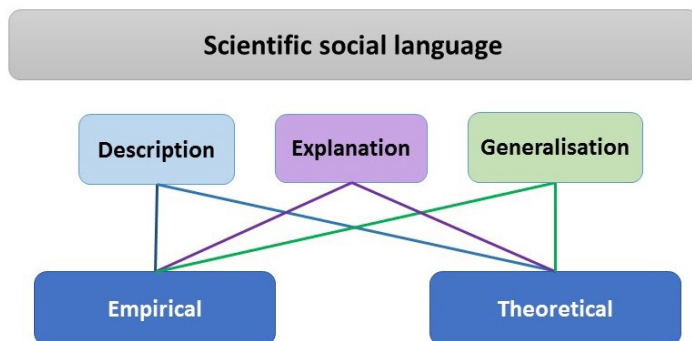


Figure 1. Framework for analysis developed from Mortimer and Scott (2003).

Table 1. The three fundamental features of scientific social language from Mortimer & Scott (2003).

Categories	Definition
Description	Involves statements that provide an account of a system, an object or a phenomenon in terms of its constituents or the spatiotemporal displacements of those constituents.
Explanation	Involves importing some form of theoretical model or mechanism to account for a specific phenomenon.
Generalisation	Involves making a description or explanation that is independent of any specific context.

Empirical and theoretical – From macroscopic to microscopic

Explanations of empirically observable phenomena, such as phase transitions, rely on understanding the behaviour of sub-microscopic particles, which is a theoretical level of knowledge. Because these particles are invisible, one must rely on representations such as models, diagrams and equations to describe them. Johnstone (1991) argued that chemistry is difficult for students because it involves thought at three different levels: the macroscopic, the sub-microscopic and the symbolic, often referred to as the “chemical triplet”. Such abstract theoretical ideas are challenging for learners (Harrison & Treagust, 1996; Johnson, 1998; Taber, 2005).

Taber (2013) argued that teachers must be aware of the importance of modelling how chemists operate with and between the macroscopic domain and the theoretical, sub-microscopic domain. Some studies have suggested that understanding chemistry improves with better modelling skills (e.g. Chittleborough & Treagust, 2007; Kozma & Russel, 1997). More specifically, Chittleborough and Treagust (2007) emphasised that students with higher modelling abilities could develop higher-order thinking processes about the chemistry they were learning. For instance, they could use models to test, predict and evaluate their ideas; develop mental pictures of the sub-microscopic level of matter; and transfer ideas between different levels of representation. According to Chittleborough and Treagust (2007),

these modelling skills should be explicitly taught, and students should practice applying multiple representations.

Nakleh and colleagues examined middle school (Nakleh, Samarapungavan & Saglam, 2005) and elementary school students (Nakleh & Samarapungavan, 1999) developing their understanding of the nature of matter. They suggested that the understanding of matter is fragmented for both young children and middle school children. More specifically, Nakleh and Samarapungavan (1999) reported that young elementary school children appeared to have descriptive rather than explanatory belief systems, in which many observable properties of matter are treated as intrinsic properties that are self-explanatory. They suggest that school instruction on the nature of matter must help children transition from thinking about the macroscopic properties of matter to thinking about the microscopic particles that explain those macroscopic properties (Nakleh & Samarapungavan, 1999).

The PNM is a competence objective of the elementary school natural science subject curriculum in Norway¹. We analyse how PSTs apply this knowledge in a practical setting and compare their application to the findings of Nakleh and Samarapungavan (1999, 2005).

Our study

We investigated whether an inquiry-based approach could provide the support PSTs needed to practice scientific social language and talk about matter on a microscopic level and/or use scientific models concerning the PNM. Our theoretical perspectives on learning about the PNM in inquiry-based science are based on the three fundamental features of scientific social language (description, explanation and generalisation) and empirical and theoretical subcategories. The frameworks depicted in Table 1 and Figure 1 were guidelines when analysing how PSTs interacted through inquiry-based activities.

A growing body of research indicates that actively engaging students in the learning process through scientific investigation is more likely to increase understanding than traditional instruction, which relies on more passive knowledge transmission (Anderson, 2002; Hmelo-Silver, Duncan, & Chinn, 2007; Minner, Levy, & Century, 2010).

Our hypothesis is that an inquiry-based curriculum would provide rich opportunities for PSTs to describe, explain and generalise. The framework of scientific social language is valuable because it allows us to analyse whether the PSTs are mainly describing, explaining or generalising as well analyse the characteristics of their communication in each category.

The participants are expected to include theoretical knowledge in their talk – specifically, to refer to the micro level by using models of the PNM to which they had been introduced throughout the teaching materials. The framework of scientific social language also allows us to examine whether and how the PSTs use empirical and theoretical levels of knowledge and thus to what extent they alternate between the macroscopic and microscopic worlds.

Our research questions are as follows:

1. How do inquiry-based teaching materials about phase changes developed for grades 5–7 facilitate pre-service teachers’ use of the fundamental features of scientific social language?
2. In what ways do pre-service teachers’ social language include expressions on the empirical and theoretical level when making meaning of the PNM?

¹ Available at <https://www.udir.no/lk20/nat01-04>

METHOD

Context of the study

The participants in the study were our own PSTs in the first year of their five-year teacher-education programme for primary teachers at a Norwegian university. There were, in total, 22 PSTs, 17 females and five males, all in their early twenties. All participated in an introductory science teaching course that consisted mainly of physics, chemistry and didactics, with some biology and geology. The participants' backgrounds in science from high school were, for the most part, a one-year mandatory course. Thirteen had completed the mandatory natural science course, with five classes per week over one year. Five participants had also completed one physics or chemistry course, and four had studied both physics and chemistry courses in high school.

The data were collected in a science class setting during an inquiry-based activity. Pre-service teachers worked in pairs. Two teacher educators were responsible for the session and took turns teaching and guiding PSTs in their inquiry. The recorded pairs were numbered, and each partner was assigned a letter. For example, the participants in pair 1 were named PST 1 and the individual students PST 1A and PST 1B. The PSTs were asked to observe what happened on the outside of a beaker filled with a mixture of salt and ice, as specified in the teaching materials. If the PSTs did not begin generating explanations on their own, they were prompted by the teachers. This was the case in one of the recorded groups.

Teaching materials

The PSTs were carrying out the unit "Models" from the integrated inquiry-based science and literacy curriculum *Seeds of Science, Roots of Reading* (Barber, 2009) developed by Lawrence Hall of Science² and translated to Norwegian by the Norwegian Centre for Science Education³. *Seeds of Science, Roots of Reading* includes several units covering a variety of topics within the sciences (life science, physical science and earth science). The units are characterised by a Do-it, Talk-it, Read-it and Write-it approach, in which students learn science concepts in depth while also learning how to read, write and discuss in an inquiry-based setting (Cervetti, Pearson, Bravo, & Barber, 2006). The teaching material was developed for pupils in grades 5–7. The topics "phase changes" and "PNM models" are part 2 of the unit "Models". The topics were taught for two 180-minute teaching sessions on separate days (Table 2). The reading sessions and final explanation sessions were done as homework. These were mandatory, and worksheets or papers were collected.

The unit "Models" introduces students to several PNM models, including particulate models of phase change, including a two-dimensional (2D) dot model, in which particles are represented as dots on a paper; a three-dimensional (3D) pearl model, in which pearls in a petri dish represent particles; and a classroom model, in which students represent particles. The teaching materials also introduce the students to the relationship between energy and phase transitions, as well as the scientific concepts for the various phase changes. Throughout the teaching session, students read, write and discuss.

Based on what they learned from the sessions prior to the recorded session, it was reasonable to expect that the PSTs would be able to use models for the PNM in their conversations about phase transitions on a sub-microscopic level. They should also be able to discuss energy transfer during phase transitions and identify which substances participate in such energy transfer.

² https://www.lawrencehallofscience.org/programs_for_schools/curriculum

³ Available from <http://www.naturfag.no>

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Table 2. Outline of “Models”, part 2. The sequence reflects the adaptations made to fit the course schedule.

Session	Description
2.3	Reading the book <i>Phase Change at Extreme Temperatures</i> (homework)
2.1	Practical inquiry into melting
2.2	Introducing several models of the PNM
2.4	Writing an explanation of melting
2.5	Understanding phase transitions
2.8	Reading the book <i>Science You Cannot See</i> (homework)
2.6	<i>Recorded session: Practical inquiry on condensation and frost formation</i>
2.7	Evaluating and revising models of the PNM
2.9	Understanding phase transitions, part 2
2.10	Writing an explanation of a mystery – adapted to writing an explanation of session 2.6 (homework)

Data sources

The data material consists of video recordings of the practical investigation in session 2.6. The video recordings included four PST pairs and were conducted with a headcam. The PST pairs were chosen randomly from the participants who agreed to video and audio recording.

The Norwegian Social Science Data Services (NSD) approved the use of the headcam and voice recorder as observational tools. All participants signed informed-consent forms stating that they could withdraw from the research project at any time, that their anonymity would be ensured and that the headcam videos would be stored securely. Efforts were made to avoid recording participants who did not consent to being filmed.

Analysis

This study examines PSTs’ communication of the PNM during an inquiry into a phase transition, the condensation of water on the outside of a beaker of ice and salt. In the analysis, verbal communication during the inquiry was coded based on whether the participants described, explained or generalised the phenomenon in question strictly following the definition of the codes developed by Mortimer and Scott (2003) (see Figure 1 and definitions in Table 1).

In our study, *empirical* (see Figure 2) includes matter on a macroscopic level and the temperature measured, which is directly observable, while *theoretical* (see Figure 2) includes matter on a microscopic level as well as energy transfer on both the macro and micro levels, as the PSTs must use theory to talk about these transfers. Table 3 contains a detailed description of the codes, which are adapted from Nakleh and Samarapungavan (1999). See examples of how the different codes were used in Table 4.

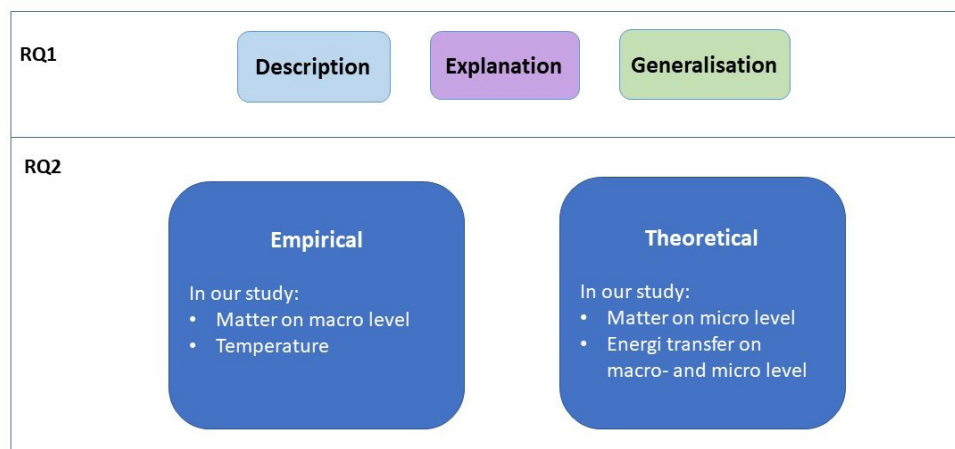


Figure 2. The figure shows how our two research questions are related to the framework for analysis developed from Mortimer and Scott (2003). It also shows what was coded as empirical and theoretical in our analysis.

Table 3. Codes used for further categorisation into empirical and theoretical.

Matter	Description, explanation or generalisation (utterance) based on observable properties or changes in observed phenomenon
Energy transfer	Description, explanation or generalisation (utterance) of energy transition specifying the substances/mediums that the energy is transferred from and to
Macro level	Utterances about matter or energy transfer on a macroscopic level
Micro level	Utterances about matter or energy transfer on a particulate level
Temperature	Utterance based on a perception of heat or a measurement of the temperature, not specifying energy transition

RESULTS AND ANALYSIS

We found that descriptions were the category of scientific social language that dominated the PSTs talk during the inquiry. For two of the groups (PST 2 and 4), all talk was exclusively in this category. For the remaining two groups (PST 1 and 3), there were a few utterances that could be categorised as explanations. Concerning the subcategories *theoretical* and *empirical*, most PSTs' talk was on an empirical level, such as descriptions and explanations related to what they could observe. PST 1 had some theoretical utterances concerning energy transition and matter on the micro level. For PST 3, there were some theoretical utterances concerning matter at the micro level, but these were related to the salt-ice mixture, not the phase transition phenomena.

Table 4 contains examples of utterances and how they were coded. Note that some utterances were difficult to categorise as either macro or micro, which is partly related to the students talking in an informal, colloquial matter. One example is, *Yes, these molecules go directly from gas to solid*. This utterance is somewhere between the macro and micro levels. The PSTs talked about the state of mat-

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ter on an empirical level (gas and solid), but the use of the word *molecule* could indicate that they were at least partly thinking about the particulate constituents of matter, so we chose to categorise this as micro.

Table 4. Examples of pre-service teacher utterances, including original utterances in Norwegian, and how they were coded according to the framework created by Mortimer and Scott (2003).

Example of pre-service teacher utterance	How it was coded
<p><i>It has frozen on the outside of the glass.</i></p> <p><i>Norwegian: Det har fryse på på glasset på utsida.</i></p>	Description – Empirical – Matter – Macro level
<p><i>Because it must come from somewhere, the vapour on the outside. It doesn't come from the inside. The water on the outside must come from the air.</i></p> <p><i>Norwegian: For det må jo komme frå når plass herre dampen utenpå. Vannet utenpå må jo komme fra lufta.</i></p>	Explanation – Empirical – Matter – Macro level
<p><i>Yes, these molecules go directly from gas to solid.</i></p> <p><i>Norwegian: Ja, disse molekylene går rett fra gass til fast.</i></p>	Explanation – Theoretical – Matter – Micro level
<p><i>Yes, the heat in the room takes part in transferring energy to the ice, so it melts.</i></p> <p><i>Norwegian: Ja, varmen i rommet da, det er den som er med på å tilføre energi til isen, sånn at den smelter.</i></p>	Explanation – Theoretical – Energy – Macro level
<p><i>The gas . . . the water molecules in the air . . . transfer energy to this [pointing at the inside of the beaker] and becomes a solid on the outside.</i></p> <p><i>Norwegian: Gassen.. vannmolekylan i lufta</i></p> <p><i>..gir fra seg energi</i></p> <p><i>..gir fra seg energi te herre her da [peker oppi glasset] og blir te fast stoff utenpå her.</i></p>	Explanation – Theoretical – Energy – Micro level
<p><i>The glass becomes colder.</i></p> <p><i>Norwegian: Glasset blir jo kaldere.</i></p>	Description – Empirical – Temperature

To answer the research questions, an in-depth analysis of PST interactions during the inquiry-based activity was performed. The results related to our two research questions are presented in the following sections. First, we present how the inquiry-based curriculum facilitated the fundamental features of scientific social language, and second, we present how PSTs' talk related to expressions on the empirical and theoretical level.

The fundamental features of scientific social language

Our analyses revealed that descriptions were the dominating feature of the PSTs' scientific social language in all four groups. There were also a few examples of explanations. There were no utterances that could be categorised as generalisation, according to the definition proposed by Mortimer and

Scott (2003). Observations were the basis for the descriptions, and PSTs used a rich variety of observations to back up their descriptions. All groups observed the phenomenon visually with and without a magnifying glass and touched the condensed water and ice on the outside of the beaker. One group even used their olfactory senses to observe the content of the beaker. Examples of student observations can be seen in Figure 3 and in the following quotations.



Figure 3. Pre-service teachers observe the frost layer on the beaker using a magnifying glass and touching the beaker.

PST 1A: Do you smell something?

PST 1B: [Bends down and smells the content of the beaker and then touches the outside] What is this?

PST 1A: Dew?

PST 1B: Oh, it is frost.

Touching the ice layer especially seemed to help them connect their observations to the types of ice they had experienced in their everyday lives. An example of this is provided here:

PST 2A: [touches the outside of the beaker with her finger] It's becoming the kind of ice that is on windows.

PST 2B: Oh, has it become frozen? [Touches the beaker with his finger] Oh wow! Okay!

PST 2A: It is like a thin ice frost layer.

PST 2B: I call it frost.

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We also registered that the observations promoted the use of scientific language and discussions of scientific concepts. Two of the PST pairs also connected their observations to other phenomena from their everyday lives, as is shown in the previous and following conversation:

PST 3A: Because if you imagine going out and looking at the grass where it is frozen, because frost has formed, right? Has it not been in a liquid state before it froze? There is no way you could tell?

PST 3B: I think it happens so fast that . . . that you would count it as frozen.

PST 3A: Yes.

PST 3B: That's what I am thinking. Because if it was in a liquid state, it would run down, and then it would freeze.

PST 3A: Yes.

PST 3B: True, it crystalises at once.

They focused on general concepts to describe phase transitions, such as the states of solid, liquid and gas. The specific concepts of water's phase transitions were not introduced before the activity. Our results showed that three of the pairs struggled to find the correct concepts for the different states of water and the phase transitions, as exemplified below:

PST 3A: But frost, that is from gas state to liquid, not gas to solid state, isn't it?

PST 3B: Frost is frozen, isn't it?

PST 3A: Oh, is it?

PST 3B: Yes, dew is . . . dew is . . .

PST 3A: Yes, dew, yes.

PST 3B: It's not frozen.

PST 3A: That's right.

PST 3B: Condensation.

Although descriptions were expected to be the predominant category of scientific social language, it was somewhat surprising that so little of the PST talk could be characterized as attempts to explain the phenomenon in question. Only one pair spontaneously attempted to explain what they observed, and this explanation was provided very quickly by one of the PSTs, with a confirmation from the partner:

PST 3A: What is on the outside is not water from there [pointing into the beaker], but water from . . . [pointing into the air].

PST 3B: The air, yes.

There are no more attempts to explain the condensation after that. This PST pair did, however, attempt to explain the low temperature of the ice and salt mixture.

Also, PST 1 started to explain the phenomenon only after the teacher prompted them to. Here, there was a great deal more discussion between the partners about how they could explain the phenomenon of condensation and frost formation. This will be discussed in more detail below.

Talk on a theoretical or empirical level

The descriptions were mainly on an empirical level. The PSTs described what they could directly observe. The descriptions of the substances were mainly on the macro level, and PSTs mainly mentioned the temperature and not energy transfer from one substance to another.

PST 3B: Yes, the glass is colder than zero degrees, so here, it changes directly from gas to a solid state. We are skipping the water state.

The one PST pair that provided a spontaneous explanation talked about matter mainly on the macro level, which is categorised as empirical. They did, however, make a short attempt to explain the energy transfer on the macro level, which is a theoretical explanation because the energy is not directly observable.

PST 3B: *It is the heat from the outside that melts it slowly.* [Talking about the melting of the ice inside the beaker.]

One pair talked about water molecules from the air condensing on the beaker only after the teacher specifically asked them to do so and after consulting the textbook. They used both the empirical and theoretical levels in their explanation.

PST 1B: *The water vapour in the air transfers . . . or the ice transfers . . .*

PST 1A: *The energy . . .*

PST 1B: *The energy of the gas in the air, so it becomes ice on the outside. Do you understand what I am saying?*

PST 1A: *No.*

PST 1B: *Because this must come from somewhere* [points at the beaker], *the vapour on the outside. It is not coming from the inside* [points to the inside of the beaker]. *The water must come from the air.*

Here, the PSTs discussed matter on a macro level, and they could at least explain that the gas must transfer some of its energy to change state to liquid. By looking more closely at the figures in the textbook, they could also develop this explanation to include matter on a micro level (Figure 4).

PST 1B: *The gas . . . the water molecules in the air.*

PST 1A: *Transfer energy.*

PST 1B: *Transfer energy to this* [points into the beaker] *and becomes solid state outside here.*

PST 1A: *Yes.*



Figure 4. A student pair using the textbook to help develop their explanation of matter on the micro level.

DISCUSSION

The PNM is a central topic in Norwegian primary schools and was considered known and understood to some degree by the PSTs. The teaching materials used in our study was developed for grades 5–7. The learning outcome from these teaching materials was expected to be mainly the inquiry-based teaching methods for teaching the PNM model to primary school children. Studying the use of these inquiry-based teaching materials, however, showed that PSTs’ understanding of the PNM that was not previously obtained via traditional teaching. The unit “Models” from the *Seeds of Science, Roots of Reading* worked quite well for the PSTs, allowing them to gain new insights into the PNM models. This study has revealed that PSTs need training in talking about and using models. This is especially relevant for PSTs, as they will need to consider the same when teaching their pupils.

The fundamental features of scientific social language

Observation is regarded as a fundamental science skill that students must practice. However, researchers argue that scientific observation requires theory and disciplinary knowledge and that it must be learned (Eberbach & Crowley, 2009; Leach & Scott, 2003; Mortimer & Scott, 2003). Asking the PSTs to observe led them to seriously observe the experiment using several senses. They apparently needed to touch the ice on the outside of the glass to be sure the water was frozen, emphasizing the value of using practical inquiries in addition to teaching materials, such as illustrations and animations. There were some observations of PSTs mentioning irrelevant features, such as smell, which is typical for everyday observers (Eberbach & Crowley, 2009). This underscores the point that observation is challenging, and that disciplinary knowledge is needed to filter, focus and foster understanding. The teacher has a key role in introducing students to this scientific way of thinking about the world (Leach & Scott, 2003).

Descriptions were expected to predominate because the PSTs had been asked to observe what happened on the outside of the beaker. However, it was not expected that most of the PSTs did not try to explain what they observed; very little talk could be categorised as explanation. The day before, they had worked with different particle models and completed an inquiry about ice melting in which they were asked to write a short explanation and afterwards learned about phase transitions. Therefore, they were expected to use some PNM models with which they had worked. It was also believed that the experiment would motivate the PSTs to try to find an explanation for the phenomenon.

One reason the PSTs spent little time explaining the phenomenon could be that they thought that the low temperature of the glass was a sufficient explanation. It may have been self-evident for them that condensation occurred because they are used to dew forming on surfaces with low temperature and ice forming at negative temperatures. This is in accordance with the findings of Nakleh and Samarapungavan (1999) that students often have descriptive rather than explanatory belief systems, in which many observable properties of matter are treated as intrinsic properties. For instance, when elementary school children attempt to provide causal explanations for phase transition phenomena, the causal models are rather shallow, with the children saying, for example, that a phase transition occurs when a substance loses or gains properties such as heat or cold. It seems as if this could also be the case for university students unless they are asked to explain.

We observed that three of the PST pairs found the low temperature of the ice and salt mixture interesting, and one pair had a longer discussion about the low melting point of ice in this mixture. Teachers should evaluate whether these discussions that fall outside of main topics are relevant for students’ learning outcomes or if it is better to eliminate such opportunities from the experiments. In our case, the low temperature was necessary for frost formation on the glass, and the PSTs were surprised to find ice when they touched the glass. This encouraged discussions about whether a substance can transform directly from a gas to solid form. It allowed the PSTs to improve their observational skills and use scientific social language. However, it would have been possible to use only ice in the beaker to make the PSTs focus on the condensation of water and the PNM models they had learned.

During their observations, the PST struggled with finding the correct concepts for the various phases of water. Observing and describing the experiment seemed to increase the PSTs' awareness of the various scientific concepts. For example, PST 3 asked the teacher about the specific words used in describing the phase transition of water from gas to solid, an example of the integrated inquiry-based curriculum providing opportunities for students to engage in active thinking about concepts. This supports the suggestion of Bravo, Cervetti, Hiebert, and Pearson (2008) that science may be a fertile context for vocabulary learning, giving students a language to voice the depth of their understanding, that is, creating descriptions using scientific terminology.

Talk on a theoretical or empirical level

Our results show that the PSTs both described and explained mainly on an empirical level. Mortimer and Scott (2003) emphasised that descriptions can also exist at a theoretical level. For example, the PSTs could have talked about particles in their descriptions or used the particle model to describe the movement of the particles in the various phases they observed.

Because the PSTs mainly used the empirical level, they also talked little about energy transfer, which is theoretical because it cannot be directly observed. The lack of talk about energy transfer was unexpected because the teaching material had focused on energy transfer in phase transitions. The one pair (PST 3) that mentioned energy transfer spontaneously did so briefly and in very few words. Energy transfer was not precisely explained in their talk. They only specified that heat from the outside must have melted the ice inside the beaker. The one exception was PST 1. When prompted to explain, they managed to develop their explanation at a theoretical level by using the textbook. These PSTs also explained the energy transfer on both the macro and micro levels, specifying energy transfer between the substances and between the particles.

This underscores that teachers should determine when PSTs need guidance and ensure they know they can use the textbook as guidance in the learning phase. It also emphasises how much information the teacher can acquire about students' meaning-making from listening to their talk, and it is a reminder of how a prompt from the teacher can improve the quality of student-student communication.

Our results indicate that during an inquiry, PSTs should be challenged to discuss the theory with which they are struggling and not only discuss what they already know and understand. Here, our results are consistent with Chittleborough and Treagust (2007), who propose that modelling is not an instinctive skill when learning chemistry and that the ability to model impacts students' mental models of matter, so modelling skills should be taught by being incorporated into instruction and by giving students opportunities to apply multiple representations of chemicals and their interactions.

The teaching materials used in this study were designed for school children, and for this age group, it is probably valuable to limit the exercise to training observation. For the university-level PSTs, in addition to observation, it was necessary to prompt them to use both theoretical and empirical explanations. Adapting the inquiry session to the PSTs' level could easily have been accomplished by also asking them to describe the phenomenon on a particle level and then asking them to explain what happened using the models they had already learned. This is an idea for teachers to use with high-performing students in their classes.

CONCLUDING REMARKS

Since the study had few participants, we make no generalisable claims; however, our findings are consistent with other studies. Our results suggest that teaching material from an inquiry-based science curriculum could facilitate rich communication between PSTs via various features of scientific social language and their practice of scientific observation via the use of several senses. According to our findings, teachers should be aware of these fundamental features of scientific social language, as

practicing them is key to learning science. The study suggests that PSTs mainly provide descriptions and explanations on the observational, empirical level. There were few examples of utterances on a theoretical level. Because depth of understanding in chemistry is related to how easily students can navigate between the macro and micro levels, this is something that students should be trained to do. Our study indicates that teachers should explicitly instruct students to use theoretical models, such as models for the PNM, in their descriptions and explanations.

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