Fifth grade science students’ modelling performance when using a particle model of matter to explain different phenomena connected to phase transitions

Abstract:
Models and modelling are key features in science. A particle model of matter is a basic model to explain the properties of substances and phase transitions. This study aims to gain insight into the modelling skills of 5th grade students who had been explicitly taught about models and a particle model of matter. The students’ ability to transfer their understanding of the particle model of matter to new contexts was studied, to see if prior modelling knowledge was transferable. The results showed that the students had an increase in sophistication level in their models, understood what needed to be included in a drawn model, and were also able to transfer some knowledge to a new context. This highlights how working with models and modelling helps students understand which explanatory entities are important when creating models in scientific teaching.

INTRODUCTION
The Norwegian National Curriculum was recently changed to emphasise working with scientific models and modelling (Norwegian Directorate for Education and Training, 2020). Specific criteria were incorporated to gain a better understanding of why and how models are used in science. For example, 4th grade students are expected to be able to “compare models with observations and talk about how we use models in natural science”, and 10th grade students are expected to “use and make models to predict or describe natural-science processes and systems, and explain the strengths and limitations of the models” (Norwegian Directorate for Education and Training, 2020).

In an international context, the use of models in science teaching has been extensively studied (Gilbert, 2004; Gilbert et al., 1998; Harrison & Treagust, 2000; Schwarz & White, 2005), but in Norway, this topic has received little attention (Bungum, 2008; Saure et al., 2021; Aalbergsoj & Sollid, 2021). With the recent shift in the Norwegian National Curriculum to further the use of models in science teaching, it is reasonable to expect a gap in the teachers’ knowledge regarding how to implement models as tools to explain, predict and communicate scientific phenomena, ideas and processes. This shift may also influence whether, and how, students learn to use and construct models.
In this study, 5th grade students were observed during a teaching unit concerning phase transitions and models. The students created their own explanations and drew models after performing experiments and observing two phenomena connected to phase transition.

The aim was to gain insight into how these students used their models, texts and knowledge to explain what happened in the context of a particle model of matter and phase transitions.

**Theoretical framework**

One of the major goals of scientific models is to link real-world experiences and scientific theory (Gilbert, 2004). Scientific models are therefore important tools in science and science education (Gilbert, 2004; Harrison & Treagust, 2000; Schwarz & White, 2005). In science education research, there is no clear definition of what a scientific model is, and the definition used depends on the theoretical perspective. Gilbert, Boulter and Elmer (2000) defined a scientific model as a representation of a phenomenon such as an idea, object, event, process or system. Others have defined a scientific model as an abstract representation of phenomena, systems or objects, focusing on the key features used to make explanations and predictions (Harrison & Treagust, 2000; Schwarz, Reiser, Davis, et al., 2009; Schwarz, Reiser, Fortus, et al., 2009). Depending on the purpose, models can be abstract, theoretical or concrete (Harrison & Treagust, 2000).

Models can be divided into *mental models* and *expressed models* (Gilbert, 2004; Gilbert et al., 2000). Mental models are representations that are created/constructed by people, either individually or in a group. This kind of model is private and personal to the individual(s) (Gilbert, 2005; Gilbert et al., 1998, 2000). A personal mental model can be used in communication with others, and when a version of the mental model is shared, it is called an expressed model (Gilbert, 2005; Gilbert et al., 1998). The relationship between one person’s mental model and the resulting expressed model is complex (Gilbert et al., 2000), but an expressed model may give some indication of a mental model (Chittleborough & Treagust, 2009). If the mental model is expressed, this act of expression will influence the person’s mental model, thereby having the potential to change it (Gilbert, Boulter, & Rutherford, 1998; Gilbert & Boulter, 2000). An expressed model may be used to form a mental model for others (Gilbert et al., 1998).

Expressed models that are agreed to be of value, after experimenting and discussion, by any social group, are termed *consensus models* (Coll & Treagust, 2003; Gilbert, 2004; Gilbert et al., 2000). Consensus models that have been carefully tested, published in a refereed journal and accepted in the scientific community are termed *scientific models* (Coll & Treagust, 2003; Gilbert, 2004; Gilbert et al., 2000). Models that are used in teaching to aid in the understanding of phenomena, processes and scientific models are called *teaching models* (Coll & Treagust, 2003; Gilbert et al., 2000). Teaching models might be different to consensus and scientific models that represent the same phenomenon or process (Coll & Treagust, 2003). Teaching models are mental models presented by teachers that should match the needs of the students, whereas consensus and scientific models are models that have been agreed on by leading scientists working in the field (Coll & Treagust, 2003). Figure 1 presents a framework for the four model types (teaching models, scientific/consensus models, mental models and expressed models) and their role in learning (Chittleborough et al., 2005). In this paper, a mental model is defined as an abstract representation of a phenomenon, system or object that is personal or private. Teaching, scientific or expressed models are defined as theoretical or concrete representations of a phenomenon, system or object.
All models are created through a process of looking for similarities, and differences, analogies (Gilbert et al., 1998; Gilbert & Justi, 2016). To explain conceptual phenomena, teachers often use analogical models (Gilbert & Justi, 2016; Harrison & Treagust, 2000), so students must be able to understand what an analogy is at the ‘abstraction level’ in order to be able to discuss models and to engage in the modelling process (Gilbert, 2004; Gilbert & Justi, 2016). The study by Saure et al. (2021) shows that, when teaching with analogical models, one should be aware that analogies can give rise to misunderstandings, so emphasising similarities and differences between the phenomenon studied and the analogical model is vital.

Models used as teaching tools may help students to create personal mental models (Chittleborough & Treagust, 2009). However, a study by Grosslight et al. (1991) shows that many students see models as copies of the real world, rather than as tools to help understand a scientific concept. This misconception may make students look for the best ‘copy’ among the models that are presented to them, instead of seeing the value of all the models presented (Grosslight et al., 1991; Harrison & Treagust, 2000).

Working with scientific models not only includes creating and using the models, but also evaluating and revising them (Schwarz, Reiser, Davis, et al., 2009; Schwarz, Reiser, Fortus, et al., 2009). As students use models, receive feedback, make predictions and adjust their understanding, the mental models are developed and adjusted accordingly (Cheng & Brown, 2007; Chittleborough & Treagust, 2009; Schwarz, Reiser, Davis, et al., 2009). In addition, involving students in modelling practices could improve the students’ meta-modelling knowledge – i.e., knowledge about the purpose and nature of scientific models (Schwarz & White, 2005). Schwarz and White (2005) argue that, without meta-modelling knowledge, students are not able to fully understand the nature of science, and their ability to create and use scientific models will be hindered.

In their study of students from several elementary and middle school classrooms, Schwarz and colleagues (2009) found that it was sometimes difficult to distinguish whether the lack of sophistication of a student’s expressed model was due to a lack of relevant content knowledge or a lack of sophistication in their view of modelling. However, the students’ reflections after taking part in a designed six-week modelling unit showed that they had learned that the inclusion of explanatory mechanisms in their scientific model was important (Schwarz, Reiser, Davis, et al., 2009). This is supported by Bamberger and Davis (2013), who claimed that students were able to improve their models, relative to their understanding and background knowledge, when receiving model-based instructions.
Aim of the study
The increased focus on models and modelling in the 2020 Norwegian National Curriculum necessitates a closer look at the understanding of models and modelling skills among students. In the 5th to 7th grades, students are expected to learn how to “use and assess models that represent phenomena that cannot be observed directly and explain why models are used in natural sciences”. In addition, they are also expected to learn to “use a particle model of matter to explain phase transitions and the properties of solids, liquids and gases” (Norwegian Directorate for Education and Training, 2020).

A particle model of matter is a fundamental idea of science, and provides a basis for understanding the properties of substances, states of matter and phase changes (Merritt & Krajcik, 2013). For students to understand the principles and theories of physical and chemical change, they must first have an appropriate understanding of matter (Liu & Lesniak, 2004).

This study explores modelling skills and the ability of 5th grade students to use a particle model of matter to explain phase transitions in different contexts.

The research questions are as follows:

1. How do 5th grade students explain different phenomena with the help of a particle model of matter?
2. To what extent are 5th grade students able to use a particle model of matter in different contexts?

METHOD
The method section will describe the context of the study, information about the teacher and the students, and how data was collected and analysed.

Context and background information
This study was performed in a 5th grade elementary school in the Norwegian county of Innlandet. The elementary school has a focus on natural sciences, and the participating class was working with phase transitions. The class consisted of 26 students (10 boys and 16 girls), aged 10 or 11 years. One student did not consent to participate and was excluded from the study. The science teacher had a background in chemistry and knowledge of the Seeds of Science/Roots of Reading concept (see below), but was not familiar with the teaching unit used in this study. Before taking part in the teaching unit, the students had had a couple of lessons about water and the three phases of water observable under normal circumstances. Therefore, the idea of phase transitions was not completely new to them. The idea of modelling was, however, novel to all students in the study. The class had lessons in the subject of natural science (60 minutes) once per week.

The science teacher followed a teaching unit called ‘Models of Matter derived from the American ‘Seeds of Science/Roots of Reading’ programme (Cervetti et al., 2006). The programme advocates a ‘do it, say it, read it and write it’ approach, where students engage in inquiry-based activities to learn a set of key concepts and to understand how scientists work. The teaching unit ‘Models of Matter’ has been translated into Norwegian (Modeller i kjemi) and adapted to a Norwegian context by the Norwegian Centre for Science Education (naturfag.no). The target group for this teaching unit comprises 5th to 7th grade students (10-13 years of age). The teaching unit consists of two parts and the second part called ‘Exploring Phase Changes’ (Undersøke faseoverganger) was used in this study. The teaching unit deals with models in chemistry and phase transitions at the micro level. This unit was chosen in order to gain insight into students’ modelling performance and to understand whether performance changed as the students’ understanding of phase transition changed. An overview of the lessons in this teaching unit can be seen in Figure 2.
The teaching in the first two lessons was addressed to the entire class, but subsequent lessons were taught sequentially, with half the class present in each lesson. Both groups were taught by the same teacher.

Figure 2. An overview of the ten lessons of the teaching unit ‘Models of Matters, phase changes’, including the lessons in which data was collected. The blue boxes indicate the topic of each lesson, and the yellow boxes indicate the lessons in which data was collected.

Written explanations and model drawings were collected from the students in lessons four and ten. Those collected in lesson four were based on the melting experiment performed in lesson one. In lesson one, the students examined how different methods influenced the melting of 15 ml ice, and they suggested methods for making the ice melt faster or slower before performing the experiment. After the experiment, the class discussed which methods resulted in energy being added to, subtracted or withheld from, the ice. At the beginning of lesson four, the students were taught how to write an explanation of an experiment concerning a different phenomenon in collaboration with the teacher and the class. In lesson four, the students were given helpful starter sentences (e.g., “The ice melted faster/slower when we ...” and “This was because ...”), and they were asked to justify evidence when they wrote explanations and drew models of the melting experiment.

The written explanations and model drawings collected in lesson ten were based on observations of the phenomena presented in lessons five and nine. In lesson five, the students were asked the question: “Why can you smell the odour inside the balloon?” The teacher added some drops of odour essence inside a balloon. The balloon was blown up and the students could smell the balloon. Two hints were given before the observations were written: “When we smell different substances, one particle from the substance has reached our nose”, and “The balloon is made of rubber and has many small holes that are a thousand times larger than a particle.” The various sizes of different particles was never discussed during the teaching unit. Lesson nine presented the question: “Do saltwater and freshwater freeze in the same way?” The students observed two bottles – one containing frozen freshwater and one containing frozen saltwater. Before writing down their observations, there was a class discussion, and the students were given the hint: “The freezing point of freshwater is 0°C.” The freezing and melting points of different substances had been discussed previously when the students read the booklet “Phase transitions at extreme temperatures”, in lesson three. The water molecules’ dipole property or the interference of salt ions in the formation of ice crystals was never discussed when talking about the phenomenon of freezing salt-
Fifth grade science students’ modelling performance

water. In the tenth lesson, the students wrote explanations and drew models of either the balloon or the saltwater phenomenon. The students were encouraged to use their knowledge about observations, evidence and writing scientific explanations, as well as their knowledge of particles, atoms and molecules, phases and phase transitions. The class shared and discussed their explanations. During the teaching unit (lesson two), the students were introduced to three different models (see Figure 3). They read two booklets – one about how different substances change phase at different temperatures, and how this may be used to separate mixtures (lesson three), and one about researchers studying things they cannot see by collecting evidence and drawing conclusions (lesson eight). The students also observed dew and frost on the outside of a beaker containing crushed ice and salt (lesson six).

![](image)

Figure 3. a) The theoretical dot model, which was the only drawn model, depicts particles in different states of matter as small round dots, and shows the organisation and distance between the dots in different phases. b) In the physical bead model, particles were physically shown as beads in a Petri dish. The Petri dishes were shaken to visualise the movement of the particles in each phase. c) In the analogical classroom model, the students themselves acted as particles in all three phases of matter. Gass = Gas, Vieske = Liquid, Fast stoff = Solid

Data collection
Written material, explanations and model drawings were collected in conjunction with lessons four and ten (see Figure 2). From lesson four, 22 student texts and model drawings were collected, and from lesson ten, 24 student texts and model drawings were collected. The students’ texts and model drawings were scanned with full student disclosure and agreement. The students were not given the opportunity to verbally explain their models or what they thought when they were drawing the models, or to revise the models at a later stage of the teaching unit.

Analysis
Bamberger and Davis (2013) identified four elements as being content-independent when studying students’ abilities to transfer modelling performances across content areas. The four elements were explanation, comparativeness, abstraction and labelling. The Bamberger and Davis (2013) frame-
work for the analysis was adapted to fit this study – for example, the comparativeness element was excluded, as the students were not comparing situations in the observed phenomena. A description of the codes for analysing the students’ modelling skills is shown in Table 1. The modelling performance and the content knowledge were analysed separately. The modelling performance of the students was based on how reader-friendly the student’s model was, and not on the accuracy of the scientific content.

Table 1. Coding scheme with descriptions for analysing the modelling skills of the students. Based on Bamberger and Davis (2013).

<table>
<thead>
<tr>
<th>Level</th>
<th>Explanation (how and why)</th>
<th>Abstraction (non-visible elements)</th>
<th>Labelling (reader-friendly)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A static model that describes what happened before and/or after. Snapshots of different temperatures with no process described.</td>
<td>Visible elements only, such as: the container with ice/water, the balloon</td>
<td>No labels or keys</td>
</tr>
<tr>
<td>2</td>
<td>A dynamic model that describes what happened through the process that caused the results. One/two ‘images/illustrations’ that show what happened during the experiment.</td>
<td>Invisible elements, such as: particles, motion, energy waves</td>
<td>Partial labelling and keying of some of the elements of the student’s model</td>
</tr>
<tr>
<td>3</td>
<td>A mechanistic model that describes what happened through the process, but also includes causality: the reason for the results. One/two ‘movies’ with motion in the model that show why it happened.</td>
<td>Invisible elements with a relative scale that shows scale difference in the model</td>
<td>Labelling and keying for all the elements of the student’s model</td>
</tr>
</tbody>
</table>

In the content-dependent analysis, where the students’ understanding of a particle model of matter in different contexts was analysed, Merrit’s ‘Particle Model of Matter Construct Map’ (2010) was used. The analytical framework was adapted for this study – the ‘Mixed model’ level was excluded, and the descriptions were shortened (Table 2). The written explanations and the models were analysed separately regarding the content.

Table 2. Coding scheme with descriptions for analysing the students’ understanding of a particle model of matter in different contexts. Based on Merritt (2010).

<table>
<thead>
<tr>
<th>Level</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>The explanation is wrong OR the particles are only shown in three states (solid, liquid and gas) without any connection to the experiment/phenomenon.</td>
</tr>
<tr>
<td>1</td>
<td>Descriptive model – only describes the experiment/phenomenon as observations at the macro level (without particles).</td>
</tr>
<tr>
<td>2</td>
<td>Incomplete particle model – describes the experiment/phenomenon at the micro level (particles are included). The empty space between the particles or the motion of the particles is shown/described and is relative to other states of matter – i.e., there is a different spacing/motion between the particles in the different states of matter.</td>
</tr>
</tbody>
</table>
Two researchers coded the data independently. The codes were first discussed and clarified, and then each researcher coded the explanations and model drawings for all the phenomena. After the coding, the results were compared and discussed, and all rating differences between the researchers were discussed and resolved.

**Ethical considerations**
The collected data was not considered to be sensitive in terms of the student’s health or security. The collected data was anonymous and stored and handled in accordance with regulations made by the Norwegian Centre of Research Data (NSD). The students were informed that the written texts and model drawings were going to be collected and analysed by the researcher. The students were also informed that they could choose to not share their written explanations and model drawings.

**RESULTS**
This section describes the results derived from the analysis of the student material. Some examples are included to illustrate the findings.

**Students’ modelling skills**
In the modelling skills analysis, written explanations and model drawings collected in lessons four and ten were analysed, with a focus on the modelling performance of the students. The performance was divided into Bamberger and Davis’ (2013) three categories of explanation, abstraction and labelling. For the explanation category, both written texts and model drawings were analysed separately, but for the other two categories, only the model drawings were analysed. The results from the students’ modelling skills analysis for the melting experiment (lesson four) can be seen in Figure 4, and examples of collected student material for the melting experiment can be seen in Figures 5 and 10.
Figure 4. After the melting experiment, the students wrote explanations and drew models to explain why the ice had melted faster, slower or not at all. The models were analysed regarding the students’ ability to explain the experiment (the explanation did not need to be correct). The different levels are described in the method section. One student only made a drawing without writing anything. *n* = 22 students.

The analysis of the explanations gathered from the melting experiment in lesson four varied, from only showing the three states of matter with an energy arrow, or only illustrating the macro level, to showing water particles at the micro level. The written explanations contained more details than the model drawings, and most of the students were therefore placed at Level 2 for the written text and Level 1 for the model drawings. An example is shown in Figure 5a. In the written text, the student described what happened through the process – i.e., added energy caused the particles in the ice to move apart and the particles to move more quickly. In the model drawing, particles were only illustrated in the container with a liquid (væske), but not in the container with solid material (faststoff). What happened during melting was not illustrated. The movement of particles, described in the text, was not shown, and it was stated that energy was added but not how it was added. The Level 1 model drawings typically only showed a before and after picture, and lacked an explanation of what happened in between and why (Figure 5c-d). Figure 5b shows an example of a student categorised as Level 2 for both model drawing and text. Here the student illustrated that the distance between the particles is different in solids, liquids and gases. The student also drew an arrow marked ‘add’, which could be interpreted as adding energy. In this case, the student illustrated that the addition of more energy causes the substance to change state.

Figure 5c-d shows two examples of Level 1 texts. In Figure 5c, the written explanation describes the macro level only. The written explanation in Figure 5d mentions particles, but it is not clear how energy and movement of particles are related to each other or what that has to do with melting.
Figure 5. Examples of students’ model drawings after performing the melting experiment. The written explanations have been translated into English.

In the figure: Fast stoff/Solid; Tilføre energi/Add energy; Væske/Liquid;

Written explanation:
Why did your method cause the ice to melt faster?
The ice melted faster when we shook the bottle. The ice melted faster when we had warm hands and it became warmer inside the bottle when we shook the bottle hard, so we added energy. This is because I added energy, so it caused the particles to move apart. So, then they move and go faster, so it became water.

In the figure: Tilføre/Add; Fast stoff/Solid; Væske/Liquid; Gass/Gas

Written explanation:
Why did your method cause the ice to melt faster?
The ice melted faster when we put the ice in hot water. I observed that the ice was melting fast. I added energy. After 10 minutes, everything melted. We measured 15 ml. That’s because we added energy. The particles became faster.

Written explanation:
Why did your method cause the ice to melt more slowly?
The ice melted more slowly when we put the ice outside. We saw that the ice had not melted. After 10 minutes, nothing had happened. This is because it was so cold outside that the ice gives off energy.

In the figure: Is/Ice; Genser/Sweater; Væske/Liquid

Written explanation:
Why did your method cause the ice to melt faster?
The ice melted faster when we put it on sweaters there was a lot of water at [unreadable] time. That’s because we added energy. Continue. The particles are fast.
All students except for one were categorised as Level 2 for abstraction level. One student only illustrated the melting experiment at macro level (Figure 5d). All other students illustrated particles as circles (Figure 5a-c). None of the students labelled everything in their model drawing, but most of them had partial labelling (Figure 5a, b and d), which mainly comprised the labelling of solid (fast stoff), liquid (væske) and gas (gass).

At the end of lesson ten, the students were again given the task of writing and drawing an explanation for a given phenomenon. The students could choose freely to answer the question “Why can you smell the odour inside the balloon?” or “Do saltwater and freshwater freeze in the same way?” Both questions had been addressed and discussed beforehand, and the students could talk to each other when writing an explanation and drawing a model for the chosen phenomenon. The results from the students’ modelling skills analysis for the balloon and saltwater phenomena can be seen in Figure 6, and examples of collected student material can be seen in Figures 7, 8 and 12.

![Figure 6](image.png)

Figure 6. After the students had been shown two different phenomena, they wrote an explanation and drew models to explain ‘Why can you smell the odour inside the balloon?’ or ‘Do saltwater and freshwater freeze in the same way?’. Both the explanation and the model were analysed with regard to the student’s ability to explain the experiment (the explanation did not need to be correct). The different levels are described in the method section. n = 13 students for phenomenon 3 (one student did not draw a model) and n = 10 students for phenomenon 4.
In the analysis of the students’ written explanations and model drawings from lesson ten, some students were categorised as Level 3. Figure 7 presents examples from the balloon phenomenon. One student was classified as Level 1 for all categories. The written text is short, the model drawing is at macro level, and there is a lack of labels and keys (Figure 7a). The work of a student categorised as Level 2 for all categories can be seen in Figure 7b. The model is explained at micro level, some abstract elements are illustrated, and the model drawing has partial labelling. One student was classified as Level 3 for all categories. In the text, the student explains that particles move out of the holes of the balloon due to spreading when shifting state. This student describes both what can be smelt and why it is possible to detect odour outside the balloon. The model drawing shows differences between liquid and gas, as well as abstract elements such as particles and movement of particles. It is also well labelled (Figure 7c).

**Written explanation:** Why can we smell the smells inside the balloon? There is steam through the small holes. The particles move faster and then it becomes gas.

**Text in the figure:** Partiklene beveger seg fort pga det er gass. The particles are moving fast because it is gas. Essensien som kommer ut av hullene. The essence coming out of the holes. Små hull/Small holes.

**Written explanation:** Why can we smell the smells inside the balloon? I think the smell comes out of small holes in the balloon, and the smell has gone from liquid to gas. The essence became gas and gas moves faster than liquid that moves slower, so the gas comes out of those holes. We also smell the essence on the outside so we know that there must be something that the smell comes out of, for example, holes.
Figure 7. Examples of students’ texts and model drawings after the students wrote and drew explanations for the phenomenon addressed by the question “Why can you smell the odour inside the balloon?”. The written explanations have been translated into English.

Figure 8 presents examples of the saltwater phenomenon (lesson ten). In the written explanation, only two students included why different freezing points for freshwater and saltwater were important for the results (Figure 8a).

All students except for one illustrated the result in the model drawing and not what happened during the freezing process of the two bottles (Figure 8b-c). Half of the students did not include the micro level in their model drawings and only illustrated the phenomenon at macro level (Figure 8b). Only one student had not included labelling or keys, whereas all the other students had partial labelling or keys in their model drawings (Figure 8a-c).
**Text in the figure:** Saltvann/Saltwater; Vann/Water; Fryser/Freeze; Saltvann: Ikke fryst/Saltwater: not frozen; Vann/fryst/Water: frozen

**Written explanation:** Does saltwater and freshwater freeze in the same way? Saltwater and freshwater do not freeze in the same way, because freshwater is made up of $H_2O$ but saltwater is made up of NaCl and $H_2O$. The freezing point of $H_2O$ is 0°C and the freezing point of NaCl is much higher. In solids, molecules move very slowly, but in liquid and gas they move quite fast. Saltwater did not freeze when we had it in the freezer, that is because the freezer is not colder than the freezing point of the mixture. The freshwater froze because the freezer was colder than the freezing point. In freshwater, the particles move less and less when we give off energy, it does not happen in the saltwater. In the saltwater, they move almost as fast.
One observation that was made for all the model drawings explaining the saltwater phenomenon was that the students who included particles drew the same kind of particles to illustrate both freshwater and saltwater.

**Students’ understanding of a particle model of matter**

The content-dependent analysis focused on whether the students had understood the particle model of matter introduced, and were able to use it to explain different experiments or phenomena. According to Merritt (2010), students sometimes see matter as a continuous medium without thinking of the matter as comprising smaller pieces (descriptive model). Some students understand that matter consists of atoms/molecules with spaces in between, and that it is the movement of the atoms/molecules or the different atoms/molecules that gives the matter its special properties (complete particle model) (Merritt, 2010). None of the students in this study showed an understanding of the matter at the highest level as a complete particle model.
Figure 9. After the melting experiment, the students wrote explanations and drew models to explain why the ice had melted faster, slower or not at all. Both the written explanations and the drawn models were analysed with regard to the students’ understanding and use of the particle model of matter. The different levels are described in the method section. One student only did a drawing without writing anything. n = 22 students.

In the melting experiment (lesson four), the students categorised as ‘Level 0 – wrong explanation’ often explained that ice was giving off energy although it was melting. One student explained the results of the melting experiment in lesson four as follows: “The ice melted more slowly when we put the ice in a high place. I observed that it became slower after ten minutes. We got 2 ml of water. I learned that this is because, when a substance gives off energy, the particles will move more slowly and come closer together and then the substance will be colder.” Common for all students categorised as ‘Level 1 – descriptive model’ was that they only explained what happened at the macro level. One student wrote: “It is because the ice was solid at first. After how long we hold the ice, the more energy was added, after the solid had become liquid, after that it became so hot that the liquid became gas, and it became vapour in the bottle.” The student did not mention particles at all, and the explanation was only at the macro level. For students categorised as ‘Level 2 – incomplete particle model’, a common denominator was the way in which they wrote about the movement of particles. When adding or removing energy, particles will become faster or slower, and the substance will change the state of matter. For example, one student wrote: “This is because I added energy, so it caused the particles to move apart. This made them move and go faster, so it became water.” In this example, the student included both movement and spacing between particles.

More than half of the students’ model drawings were categorised as ‘Level 2 - incomplete particle model’. Common for the Level 2 model drawings was that the students had included particles in the model drawing and showed spacing and/or movement of particles. For examples see Figure 10a. The students were categorised as ‘Level 1 - descriptive model’ if the model drawing only showed the macro level (Figure 5d). Sometimes, the student had only illustrated the different states of matter, which was categorised as a wrong explanation (Level 0), as the experiment was not illustrated (Figure 10b).
When analysing the material, the written explanations and model drawings did not always show/explain the same observations. One student wrote that energy had been removed and that the particles moved more slowly, but the model drawing showed that energy was added when the ice melted into water (Figure 10a).

When analysing the written explanations and model drawings for the chosen phenomenon, which were carried out in lesson ten, with five lessons about phase transitions and models teaching in between, there was a difference between the levels of understanding of the balloon phenomenon and the saltwater phenomenon (Figure 11).
Figure 11. After the students had been shown two different phenomena, they wrote an explanation and drew models to explain ‘Why can you smell the odour inside the balloon?’ or ‘Do saltwater and freshwater freeze in the same way?’. Both the written explanations and the models were analysed with regard to the students’ understanding and use of the particle model of matter. The different levels are described in the method section. $n = 13$ students for phenomenon 3 (one student did not draw a model) and $n = 10$ students for phenomenon 4.
In the explanation of the balloon phenomenon, one student (Level 3) wrote: “When we took up the essence which is liquid, we turned the liquid into gaseous form. Then the particles spread outwards in the balloon. The balloon has very small holes from which the gas spreads. The particles spread out faster inside the balloon and if you leave a balloon for 1 week, for example, it shrinks.” The student described the properties of the gas from a particle point of view, and stated that fast-spreading particles were the reason why the particles were able to leave the balloon through small holes. This was also illustrated in the model drawing, where the differences between the essence particles were shown in both the liquid and gas states. The difference in movement and distance was clearly illustrated (Figure 7c).

It seemed that the saltwater phenomenon was harder to explain than the balloon phenomenon. Many students mentioned the difference in freezing point, but not what caused different results in the freshwater bottle and the saltwater bottle. One student, categorised as Level 3, wrote “Saltwater and freshwater do not freeze in the same way, because freshwater is made up of H₂O but saltwater is made up of NaCl and H₂O. The freezing point of H₂O is 0°C and the freezing point of NaCl is much higher. In solids, molecules move very slowly, but in liquid and gas they move quite fast. Saltwater did not freeze when we had it in the freezer, that is because the freezer is not colder than the freezing point of the mixture. The freshwater froze because the freezer was colder than the freezing point. In freshwater, the particles move less and less when we give off energy, does not happen in saltwater. In the saltwater, they move almost as fast.” This indicates that the student understood that different substances have different properties, and that what determines the state of matter of the substance is the movement (and distance) of the particles (distance is not mentioned in the explanation). The differences in movement and distance were illustrated by two students in their model drawings of the saltwater phenomenon (Figures 8a and 12).

Text in the figure: Vann= Liquid; Salt og vann= Salt and water; Fast stoff/Solid; Bare vann= Only water

Written explanation: Does saltwater and freshwater freeze in the same way?

We took one bottle of water and another bottle of water plus salt. Saltwater and freshwater do not freeze in the same way because they do not have the same freezing point. The freshwater became a solid and the saltwater became sloppy, it is partly liquid. Molecules in solids move slowly but move slightly. In gas, the molecules move very fast and “fly” apart. In liquid, they move a little faster than solids.

Figure 12. Examples of students’ text and model drawing after the students wrote and drew explanations of the saltwater phenomenon. The written explanations have been translated into English.
DISCUSSION

The students’ modelling skills

In order to answer how 5th grade students explain different phenomena with the particle model of matter presented, the data from the melting experiment were analysed. The analysis indicates that the students were inexperienced in expressing themselves via the medium of model drawings. The corresponding written explanations often contained more information than the model drawings. Several students presented a before and after image in the model drawing, but did not describe the process in between. In the written texts, however, they described what happened to particles during the melting process. The inexperience with expressed models may be due to the lack of mental models for what happened in the experiments, and the better explanations in the written material were a reproduction of what the teacher had verbally explained. The labelling in expressed models, from the first modelling event, was either absent or insufficient to be reader-friendly. With a few exceptions, the labelling encompassed state of matter (solid, liquid, gas) and arrows labelled as adding/removing energy. No student labelled the particles to explain what they were. Moreover, only a few students tried to depict the movement of the particles.

Although three different models (the theoretical dot model, the physical bead model and the analogical classroom model) had been presented to the students, all students depicted the particles as circles as in the dot model. It has previously been suggested that students look for the best ‘replica’ among the teaching models that have been presented to them instead of seeing the value of all the teaching models (Grosslight et al., 1991; Harrison & Treagust, 2000). A simpler explanation may be that the dot model was the only model that was drawn on paper, and was therefore easier to be used by the students when asked to draw a model. Without previous experience of drawing models, it may have been easier to copy the dot model rather than translating the physical bead or analogical classroom model to paper.

At the very end of the whole teaching unit, the students who drew models showed an increased use of the labelling of elements, and the speed/movement of the particles was often indicated. This increase may indicate a learning curve, where students had a better understanding of the features that it is important to depict in a model, which is in line with the suggestions of Schwarz, Reiser and Davis et al. (2009), who claim that students’ models become more sophisticated as their view of modelling expands. Bamberger and Davis (2013) claim that students can create a better model (‘better’ relative to their understanding and background knowledge) when they receive model-based instructions.

In this study, the students were not able to revise the models they had drawn. The possible benefit of the ability to revise is the opportunity to see other students’ model drawings, to see their own mental models expressed, as well as other teaching models, and based on this, to be able to enhance their understanding (Gilbert et al., 1998; Gilbert & Boulter, 2000). If the student’s mental model changed, they might have drawn a different model. Time is another aspect, as the students needed to finish their written explanations and model drawings before the lesson ended. Some drawn models seemed to be unfinished when collected at the end of the lesson.

Understanding and use of a particle model of matter

A particle model of matter is often used to explain what substances consist of, and why substances behave differently in different states (Merritt & Krajcik, 2013). The model can also be used to explain other phenomena, such as why a smell spreads within a room and why different substances have different freezing points (Merritt & Krajcik, 2013). A comparison of the explanations and model drawings from the melting experiment with the balloon or saltwater phenomenon was not able to answer the question: “To what extent are 5th grade students able to use a particle model of matter in different contexts?” The added size aspect of particles in the balloon phenomenon, and the addition of salt to the water (where salt ions lower the melting point by disrupting the ring structure of water molecules in ice) were not discussed in class, which meant that a direct comparison was not possible. However, the results indicate an increased understanding of the particle model. Some students were able to transfer their understanding of the particle model and phase transitions, and use it in a new context.
In the melting experiment, which was performed at the beginning of the teaching unit, students were categorised as belonging to the lower levels only. It may be that the students lacked a mental model that fits the melting experiment, and chose the previously shown model just to have an explanation (Grosslight et al., 1991; Harrison & Treagust, 2000). It may also be that the students had problems in expressing their mental models both in written and drawn form. The relationship between a person’s mental model and their expressed model is complicated (Chittleborough & Treagust, 2009; Gilbert et al., 2000). It is therefore difficult to know whether an expressed model really is the same as a person’s mental model.

In the second experiment, which was conducted at the end of the teaching unit and where the students could choose between the questions: “Why can you smell the odour inside the balloon?” and “Do saltwater and freshwater freeze in the same way?”, some of the students’ explanations showed an increased sophistication level of the particle model of matter. In the balloon phenomenon, the students dealt with the differences in the properties of liquids and gases, where substances in gas states spread through the air. Some of the students seemed to be able to transfer their knowledge from the teaching unit to the balloon phenomenon. Some students illustrated the different properties of liquid and gas, and explained that the gas’s property of spreading was a key factor for the ability of the particles within the gas to escape through small holes in the balloon. The reason why the level of explanation is more sophisticated in the study of this phenomenon than in the saltwater phenomenon is perhaps due to the complexity of the latter. In the saltwater phenomenon, the students needed to deal with different freezing points, and that seemed to be harder to understand or explain. The question is whether the students understood what consequences different freezing points have for substances at the same temperature. None of the students who chose the saltwater phenomenon illustrated two or more different types of particles in their models, which indicates a lack of fundamental understanding of the phenomenon. However, mixtures had not explicitly been taught in the teaching unit, and this could easily be the reason for the lack of different particles in the students’ models.

The study shows that the students needed to be taught what to include in a model drawing, and that they seemed to be better at explaining what happened in an experiment/observed phenomenon in words than in a model drawing. There is a need to further investigate the learning progression that could happen if students are given the opportunity to revise their models. It is also important to explore whether teaching with an explicit focus on modelling will influence students’ meta-modelling knowledge.

LITERATURE


