THE USE OF ANIMATIONS IN CHEMICAL EDUCATION

Han Vermaat
Henny Kramers-Pals
University of Twente, Enschede, The Netherlands

Patricia Schank
Stanford Research Institute

Abstract

A central issue in chemistry education is the relation between the macroscopic or real world and the molecular or nanoscopic world. New students could better understand chemistry and apply their chemistry understanding to solve problems if they were able to make deeper connections between these worlds. Animations can be used in chemical education so that students get a better knowledge of molecular processes by making better relations between the macroscopic and the nanoscopic world.

Twenty 10th grade, pre-university students from four different schools were distributed into four five-student groups, students of each group attended the same school. Group 1 received instruction on paper. Group 2 students were also provided with animations that showed nanoscopic processes. Group 3 received the same material as with Group 2, but the students were also required to complete assignments and perform a number of tasks for which they had to take a closer look at the animations. Students in Group 4 were required to do everything that Group 3 were required to do, and they were asked to make animations by themselves. The students were interviewed after instruction.

Only two students (from Group 1 and 2) could give a complete, molecular explanation why ice floats on water when ice is melting. Six students (two from Group 1, three from Group 3 and one from Group 4) gave an explanation that was correct, but not complete. The other twelve students could not explain this phenomenon. Solid salt and distilled water are insulators, but a solution of salt in water conducts electricity. Students in Groups 3 and 4 could explain this when they were performing the tasks about the animations. The Group 4 students made animations that were close to the scientific accepted models, which strongly indicate that creating animations gives a strong learning effect. Nevertheless, there was not a very clear distinction between the four groups when students were interviewed two weeks after instruction.

The students came from four different schools, and had therefore different backgrounds. There will be a follow up investigation in order to get a more homogenous group, which will result in stronger conclusions.

Introduction

A computer animation is a series of rapidly changing pictures on the computer screen, which gives an illusion of motion (Large, 1996). There have to be at least fifteen pictures per second for a fluent and continuous motion. According to Mayer and Moreno (2002) an animation has three characteristics. It is a picture, it shows apparent motion, and it is simulated. This means that an animation consists of objects that are drawn or created with some other simulation method. A video shows motion of real objects. Similarly, an illustration is a static picture of a drawn or simulated object, and a photo is a static picture of a real object. Computer animations can be used in instruction programs on CD-ROM or on the Internet. Movement of so-called gif-animations cannot be stopped; the animations cycle in a loop. Other animations play via a plug-in like QuickTime or Flash[1]. QuickTime animations can be stopped, so certain details can be viewed more closely. It is possible to play animations in programs such as QuickTime or Windows Media Player, and to copy frames of the movie. This allows students to interact with the animation.

Animations can serve different roles in instruction. Weiss, Knowlton and Morrison (2000) mention decoration, gaining attention, motivation, extra information and clarification of complex knowledge or complex phenomena as potential roles of animation. Gaining attention is an important function, in which there must be overlap with the content of the accompanying text. If there is no overlap, the animation can distract from the instruction. Large (1996) argues that animations add to written information, but cannot replace it. Motion is the special quality of animations and therefore animations can promote learning of dynamic processes (Large, 1996). Since chemical processes at the molecular level are dynamic, impossible to see, and typically quite hard to imagine, animation could be a powerful tool in chemistry education. Atoms, molecules and ions are not static, but vibrate, move, collide and interact with each other. These dynamic processes are better represented in an animation than in static pictures. Molecular-level animations have been proposed as a way to support student understanding in chemistry (Burke, Greenbowee & Windschitl, 1998). The rationale is that animations make visible otherwise abstract chemical concepts, especially those related to the particulate nature of matter.

Chemistry explains many processes from the real world with the abstract concepts of atoms, molecules and ions. The size of atoms, molecules and ions is typically several nanometers, so the world of these particles is sometimes called the *nanoscopic world* (Schank & Kozma, 2002; Vermaat, 2002). Other names are the *molecular world*, *submicroscopic world* (Ebenezer, 2002), or *particle world* (Bunce & Gabel, 2002). The name microscopic world (Sanger & Greenbowee, 2000; Wu, Krajcik & Soloway, 2001) suggests that the particles can be seen through a microscope. This is not the case, so the terms nanoscopic or submicroscopic are preferred. Because atoms and molecules cannot be perceived directly, chemists work with models or representations, constructions on paper, computer-based animations, or physical constructed models that have some properties of the real object. A 'good' model shows the appropriate properties of the associated object (Dieks, 1999). A goal of instruction is that students develop *mental models* that look like *conceptual models* that are accepted by the scientific community, and that students fit these models into a structure of related knowledge (Greca & Moreira, 2000; Seel, 2003). Mental and conceptual models are contrasted in Table 1.

Table 1.*The differences between mental and conceptual models (after Greca & Moreira, 2000).*

a mental model	**a conceptual model**
is a *personal*, internal representation, used by learners (mental models can be external if learners make sketches).	is a *public*, external representation, created by researchers, teachers, experts, etc.
explains and makes predictions about an associated system.	facilitates the comprehension or the teaching of systems or states of affairs in the world.
has to be functional to the person who constructs it.	has to be useful to the (scientific) community.
is incomplete, not exact, changeable	is more complete, more exact, less changeable
grows and becomes better if new knowledge is acquired.	is more or less full-grown.
can be quite different from the real object, phenomenon, or situation it should represent.	is a simplified representation of a real object, phenomenon, or situation.

Chemists use a range of representations to understand scientific phenomena. They switch between different representations and use them in a combined fashion to solve scientific problems, to predict certain phenomena, and to communicate with other chemists. However, students typically lack both the basic knowledge and the skills to work with different representations (Kozma & Russell, 1997). Because of limitations of representational knowledge and the skills to use these representations as objects of thought, students often do not understand scientific symbols (Kozma, 2000; Seel & Winn, 1997). They could better understand chemistry and apply their chemistry understanding to solve problems if they were able to make deeper connections between reality, the molecular world and the world of chemical formulas and equations (Herron, 1996).

Students should also be prompted to make relations between the three chemical worlds. Researchers hypothesize that the difficulties students face in relating elements among the three levels are at the root of their conceptual problems (Gabel, 1998; Nakhleh, 2002). Not only should students develop mental models that are scientifically accepted, but also they should use these models to explain and/or predict macroscopic phenomena. Furthermore they should be able to translate the macroscopic and nanoscopic world into the symbolic world and vice versa. Chemists communicate by chemical symbols, formulas and equations of the symbolic world. Instruction and assessment should explicitly address the relations between the three chemical worlds.

A process that is explained in the nanoscopic world is the floating of ice on water, a concrete phenomenon that is known to most students. In nearly all substances the solid phase is denser than the liquid phase, and when both phases are mixed, the solid phase will sink. This can easily be seen if one puts a bottle of olive oil in a freezer; as the oil cools and solidifies, it forms a solid on the bottom. In the Netherlands, 9th grade students are taught a model for solid, liquid and gaseous phases (Figure 1), which explain this phenomenon (Camps, Pieren, Scheffers-Sap, Scholte & Vroemen, 2002; De Valk & Ousen, 2003; Hogenbirk, Jager, Kabel-van den Brand & Walstra, 1999). However, this model does not explain why ice floats on water. According to this model, a solid will be denser than a fluid, because in a certain volume of solid there are more molecules than in the same volume of liquid. In order to explain the lower density of ice, students have to change their mental model of ice and water.

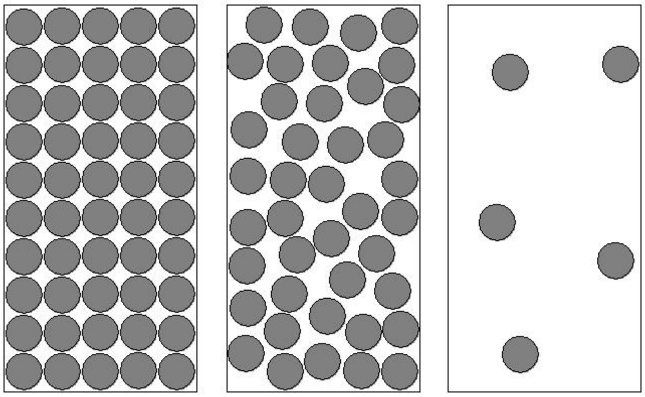

Figure 1.Models of a solid, liquid and gas, as taught in Dutch schoolbooks. Molecules in solids are immobile, in liquids there is motion, and molecules in gases don't attract each other at all.

Another familiar phenomenon is the electrical conductivity of a solution of salt in water. Pure, distilled water and solid salt (sodium chloride, NaCl) are insulators for an electrical current, while a solution of salt is a conductor. Due to the curriculum in the Netherlands, 10th grade students think that all substances consist of molecules or atoms. They know that an electric current is transfer of charge. To explain the conductivity of a solution of salt in water, students have to change their mental model of the building of substances, and to accept that there are substances that consist of charged particles.

Both the melting of ice and the dissolving of salt in water, which results in a conductor, are complex dynamic processes. Animation should therefore be a useful tool of instruction for these processes. Just showing animations in order to change the mental models of the students will probably not be enough. In an animation there are a lot of changes simultaneously, and it is difficult for students to recognize the conceptually important features of the animation (Schank & Kozma, 2002). Furthermore, students tend to hold to their old models, and disregard information that contradicts this model (Herron, 1996).

To change the mental models of the students, they should work actively with animations and recognize and comprehend the important features of the process. This can be done by completing assignments and performing tasks in which students have to take a close look at the animations. If students have to create animations by themselves, they will have to imagine carefully what the nanoscopic processes are. Students in earth science who created diagrams of what they learned about plate tectonics outperformed students who wrote summaries of their learning (Gobert & Clement, 1999). Students who make animations probably will develop strong mental models, which will be more in accordance with scientifically accepted models.

A tool that is used for students to create animations is ChemSense, a NSF-funded project by the Stanford Research Institute at Menlo Park, CA, U.S.A. (Schank & Kozma, 2002). The ChemSense team has designed software and activities to help students to connect observable, macroscopic phenomena with nanoscopic representations, and explain these phenomena in terms of the underlying, nanoscopic mechanisms. The ChemSense Studio supports the viewing, editing, and sharing of various representations, including animations. Students and instructors can comment on representations that are made by other students. Research by Schank and Kozma (2002) suggests that the use of ChemSense facilitates representational ability and understanding of nanoscopic mechanisms. The use of ChemSense requires students to think carefully through more specific aspects of chemical phenomena to which they might not otherwise attend. Students arrived at a shared understanding of the chemical content through their planning and discussion of animations.

The purpose of this study is to investigate how animations can be used in chemical education so that students gain a better understanding of molecular processes and improve their abilities to relate the nanoscopic and the macroscopic world.

Method

Participants

Twenty 10th grade, pre-university students from four different schools participated in this study. These twenty students were distributed into four five-students groups; students of each group attended the same school. In this way there was no contact between students of different groups.

Group 1 received instruction on paper (see **Materials**). Their teacher had already introduced the processes of the melting of ice and the conductivity of a salt solution during regular lessons, and the students had completed a test about these topics.

Students in Group 2 received instruction on paper too, but they were also provided with animations[2] (see **Materials**). There were no special assignments or tasks belonging to these animations, the students were just asked to take a look at them. During this investigation, these students also received instruction in their regular lessons by their own teacher about the processes.

The students in Group 3 received the same instruction materials as those of Group 2, but they were also required to complete assignments and perform a number of tasks (see **Materials**) for which they had to take a closer look at the animations. Group 3 students, just as those of Group 1, had received instruction about the processes by their own teacher during regular lessons before this research.

Group 4 students were required to do the same assignments and tasks as the Group 3 students, but they also made animations by themselves. Due to time restrictions, Group 4 students made only animations of the dissolving of salt. The students in this group were instructed by their own teacher about the processes of melting of ice and conductivity of a solution of salt *after* this research. That is, unlike Groups 1-3, Group 4 students had no prior or concurrent instruction on the relevant topics, which (in retrospect) makes it difficult to compare their results to the other groups. Some interesting results are discussed nonetheless, and this methodological limitation (which was due to logistical constraints) is discussed below and will be remedied in a future study.

Materials

The ***instruction on paper*** for the students consisted of copies from the textbook that is in use at their school. The students were asked to study these papers by themselves. For the students of Group 1, 3 and 4 these were copies from the textbook *Chemie* (Pieren, Scheffers-Sap, Scholte, Vroemen & Davids, 1999); for Group 2 students the copies came from the textbook *Curie* (Van Antwerpen, Bouma, Le Fèvre, Van Schravendijk, Schouten, Van Steeg & Termaat, 1998).

The ***animations*** shown to the students of Group 2, 3 and 4 were made by Roy Tasker of the University of Western Sydney, Australia (Tasker, Chia, Bucat & Sleet, 1996). The first animation depicted the melting of ice at the molecular level. Frames from these animations can be seen in Figure 2. The second animation depicted the dissolving of table salt (sodium chloride) in water. Group 3 and 4 students also heard a recorded voice, in English, that explained the process. The students were given a Dutch translation of this talk. In addition, there were animations of a hydrogenated chloride ion and of a hydrogenated sodium ion. Frames of these animations can be seen in Figure 3.

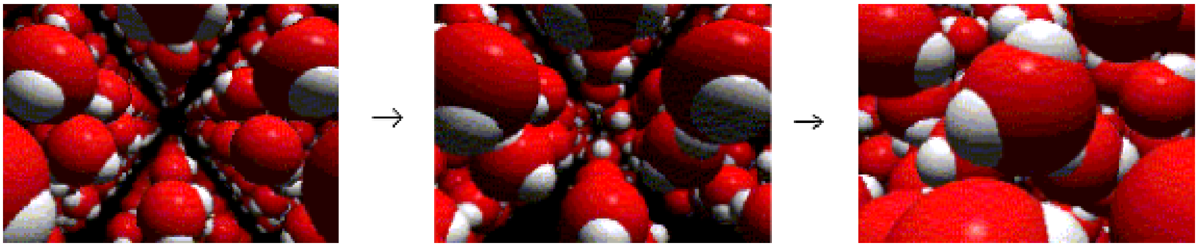

Figure 2. Frames from the animation 'Ice melting'

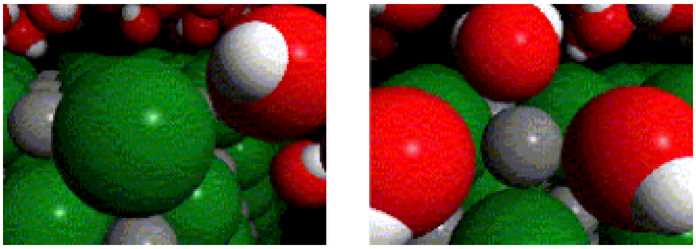

Figure 3. Frames from the animation 'Dissolving of salt'.

Students of Group 3 and 4 had to complete *the assignments* shown in Table 2 while working with the animation. Group 4 students used the ChemSense Studio[3] for making animations by themselves.

Table 2. *Assignments accompanying the animations*

Assignments for the animation 'Ice melting'

- Take a look at the animation and describe what you see.
- After how many seconds the ice starts to melt? How can you see this when looking at the water molecules?
- Where is more space between the water molecules, in ice or in liquid water?
- What is denser, ice or liquid water? Explain.
- Are there more watermolecules in a cm^3 ice, or in a cm^3 liquid water? Why?

Assignments for the animation 'Dissolving of salt'

- Are the gray balls sodium ions (Na^+ ions) or chloride ions (Cl^- ions)? Explain.
- Stop the animation at the moment the first (green) ion will be surrounded by water molecules.
- What is the charge of this ion?
- Which side of the water molecules is pointed to this ion, the side with the hydrogen atoms, or the side with the oxygen atom?
- Stop the animation at the moment the second (gray) ion will be surrounded by water molecules.
- What is the charge of this ion?
- Which side of the water molecules is pointed to this ion, the side with the hydrogen atoms, or the side with the oxygen atom?
- A water molecule is a dipole molecule, it contains a $\delta+$ and a $\delta-$ side.
- Explain that the hydrogen side of the water molecules is pointed to the chloride ion.
- Explain that the oxygen side of the water molecules is pointed to the chloride ion.

Instruments

All the students were interviewed about two weeks after the instruction. These interviews were semi-structured, the interviewer used the same open-ended questions for each student (Table 3). The interviewer asked the students to draw nanoscopic processes that show what happens if ice is melting and salt is dissolving in water in order to explain macroscopic processes.

Table 3 *The interview questions*

Questions for the phenomenon melting of ice

- What do you observe in the real world if ice is melting?
- Does ice float on water?
- What has the greatest density, ice or water?
- Can you give a molecular explanation (an explanation in which you use the word molecules) for the phenomenon that ice floats on water? Make a sketch that shows what happens to the water molecules if ice is melting, or what the difference is between water molecules in ice and in liquid water.

Questions for the phenomenon conductivity of solution of salt

- Can you describe what happens to the water molecules and the particles of which salt consists if salt is dissolved in water? Make drawings that show what happens.
- Can you explain why a solutions of salt does conduct a current and solid salt does not?

Procedure

The interviews took place about two weeks after the students had received the instruction.

Analysis

All the interviews were taped and the drawings were scanned. The results of all interviews were written down. After that, the explanations of the students were classified and analysed. Special attention was given to the nanoscopic explanation that students gave for the macroscopic processes.

Results

Melting of ice

In response to the question "What do you observe in the real world if ice is melting?" all twenty students eventually mentioned the change from a solid state to a liquid state. Eight students in their description started to talk about molecules. After the interviewer asked if they could see molecules, these students gave a macroscopic description.

All students knew that ice floats on water and does not sink to the bottom if ice is melting. Eighteen students said that ice is less dense than water (e.g., one said, "Water is of course denser than ice."). Two students, both from Group 1, thought that ice is denser than water.

The explanation of the phenomenon that ice floats on water relates to the unique arrangement of the molecules in ice and in liquid water. In ice the water molecules are held together by hydrogen bonds in a hexagonal, relatively open structure as can be seen in the left part of Figure 2. This orderly arrangement collapses during melting, and the molecules pack less uniformly but more densely (Jones & Atkins, 2000). During instruction, the students of both Group 3 and 4 formulated this explanation. However, two weeks later, no students from Group 3 or 4 were still able to give a complete explanation (Table 4). Six students were able to give an incomplete explanation, that there is more space between the molecules in ice than there is in liquid water. Half of the students held on to their old, limited model of solids and liquids shown in Figure 1. Two students invented whole new explanations involving 'surface tension' and 'loss or energy'. The last student could not explain what was meant by this concept.

Table 4 *Students' explanations why ice floats on water, two weeks after the intervention*

Group	complete explanation	in ice more space between molecules than in water	alternative explanation: 'old' model of solids and liquids	other alternative explanation
1	1	2	1	1 (surface tension)
2	1		3	1 (loss of energy)
3		3	2	
4		1	4	
totals	2	6	10	2

In sum, after two weeks, half of the subjects returned to the old model of solids and liquids, and only two students (in Groups 1 and 2) were able to give a complete, accurate explanation. Active use of animations did not lead to better explanations by Group 4 students, but this outcome could also be explained by the fact that Group 4 students had not received prior instruction on the topic. What is remarkable is how many students returned to the old model despite instruction with or without interaction with animations, illustrating how students' difficulties in understanding chemistry concepts often persist despite instruction (Gabel, 1998).

Dissolving of salt

All students knew that a solution of salt conducts an electrical current, but neither solid salt nor pure water does. The explanation for this phenomenon is that in solid salt, all the ions (charged particles) are held together by ionic bonding, so the ions cannot move. During dissolving, the ions are pulled out the ionic lattice by the water molecules. The water molecules surround the ions. The slightly positively charged hydrogen atoms in the water molecule are attracted to the negative chlorine ions, while the slightly negative oxygen atom of the water molecule is attracted to the positive sodium ions (Jones and Atkins, 2000). The sodium ions are smaller than the chlorine ions (ionic radii 98 pm and 181 pm respectively). In a solution of salt, the charged particles can move, which means that the solution can conduct a current. The students of Group 4 made animations in which they showed that they understood this process (Figure 4).

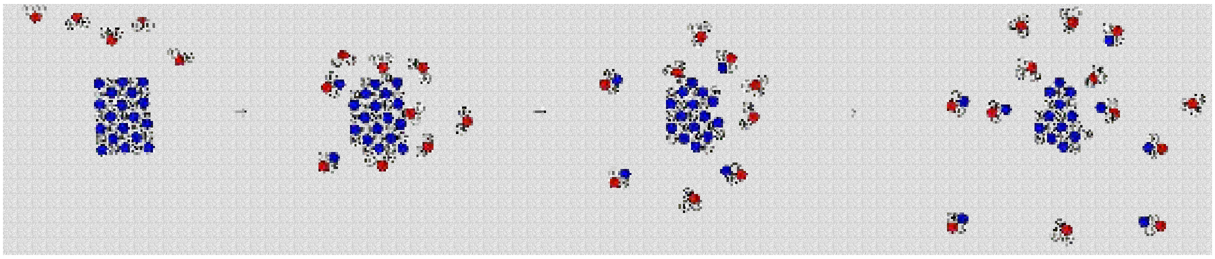

Figure 4 Frames from an animation made by a student of Group 4.

The results of the interviews are listed in Table 5. A complete explanation includes the following items:
in solid salts the ions are immobile;
in a solution the ions can move;
the sodium ions are positively charged and smaller than the negatively charged chlorine ions;
the ions in a solution are hydrated (= surrounded by water molecules);
the oxygen atoms of the water molecules are near the sodium ions, the hydrogen atoms of the water molecules are near at the chlorine ions.

In an incomplete explanation, students state that in solid salts the ions are immobile, and in a solution the ions can move, but they:
have inverted the charge or the size of the ions, and/or
drawn ions of the same size, drawn a wrong hydratation, and/or
used the formula HO_2 for water molecules, and/or
reversed the charges of the water molecule.

An alternative explanation lacks the immobility of ions in solid salt and the mobility of ions in a solution, which are the key features of this phenomenon.

Table 5Students' explanations of the phenomenon that a solution of salt conducts a electrical current, two weeks after the intervention.

Group	complete explanation	incomplete explanation (size or charge of ions, hydratation)	alternative explanation
1		4	1 (water is the conductor)
2		3	2 (hydrogen bonds; no explanation)
3		4	1 (particles vibrate)
4	1	3	1 (electrons are responsible)

Figure 5 shows two sketches made by students during their explanations. The sketch in the upper part of Figure 5 was made by a student who gave a complete explanation. This student said that the Na particles are positively charged sodium ions and that the Cl particles are negatively charged chlorine ions. The circle with the “3” in it represents an water molecule, which was sketched as in the upper right part of Figure 5. The sketch in the lower part of Figure 5 shows an incomplete explanation. Both charge and size of the sodium and chlorine ions are inverted, as is the charge within the water molecules.

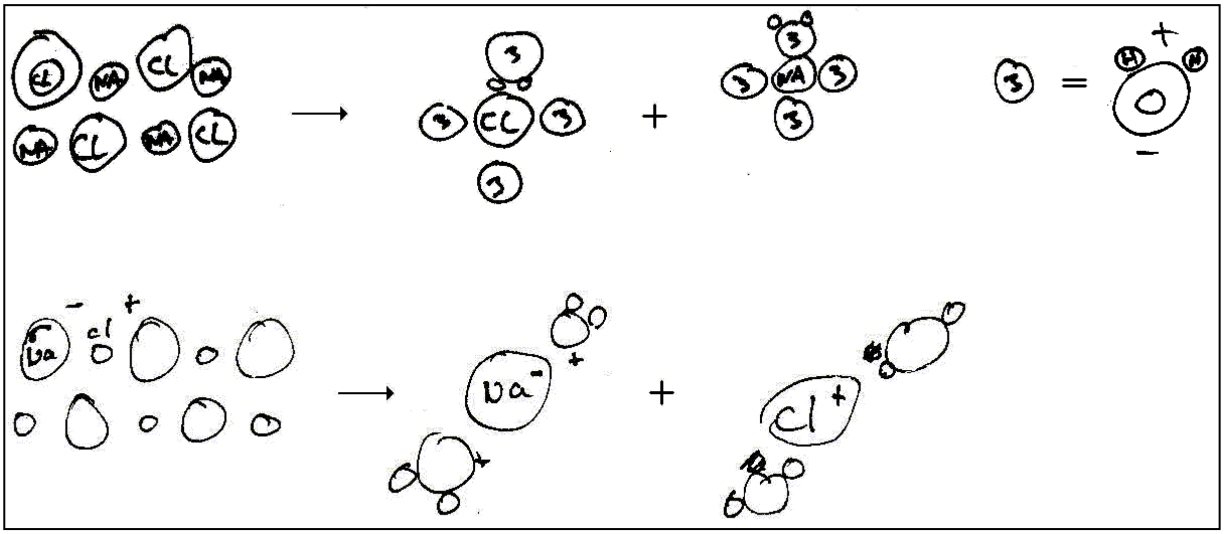

Figure 5 Sketches made by students during their explanation that solid salt does not conduct an electrical current, but a solution of salt in water does.

Discussion

It is remarkable that eight out of twenty students started to talk about water molecules when asked: “What do you see if ice is melting?” They knew this research was about the way chemistry is taught, and they probably connect the chemistry with the concept of molecules. However, this does not mean that these students actually link the molecular world to the real world. It is possible that the concept of molecules is an abstract concept, which has little meaning to them.

Half of the students held on to their old model of liquids and solids. This model is insufficient to explain the phenomenon that ice floats on water, and these students were not able to give a good explanation of these phenomena. In an informal conversation, a teacher mentioned that the model of Figure 1 has been ‘drilled’ in 9th grade students, and it may therefore be hard to change their mental model.

From the data in this research, it is not clear that an active look at the animated model of water molecules in melting ice promotes the understanding of this process. Three of the five Group 3 students gave an incomplete explanation (in ice more space between the molecules than in water. The two students who gave a complete explanation came from Groups 1 and 2. However, the students of Group 1 and 3 had already received instruction about this process before this investigation, so for them the instruction during this research is a repetition. A higher proportion of correct explanations from students in Groups 1 and 3 should therefore be expected based on their prior knowledge.

The animations made by Group 4 students are close to the scientifically accepted models. The students at once noticed some restrictions of ChemSense. They wanted to use the ionic radius for the sodium and chlorine ions, and the Van der Waals radii for the atoms in a water molecule. Furthermore, they expected green chloride atoms or chlorine ions instead of the blue ones they had to use in ChemSense. (In the time since this study was conducted, both ionic radii and more standard colors for atoms have been added to ChemSense). Even with the restrictions at the time of the study, the animations are quite detailed and accurate (Figure 4). All the significant features of the dissolving of salt are incorporated in the animation: in solid salts the ions are immobile, in a solution the ions can move, the ions in a solution are hydrated, the oxygen site of the water molecules is pointed at the sodium ions, and the hydrogen site of the water molecules is pointed at the chlorine ions. While they were making the animations, the students mentioned that the sodium ions should be smaller than the chlorine ions and that the sodium ions have a positive and the chlorine ions a negative charge. So their mental model had changed to the conceptual model.

The students of Group 1 and 3 had already received instruction about the process of the dissolving of salt, and the students of Group 2 were instructed by their own teacher during this research. The Group 4 students were instructed by their own teacher *after* this research. This difference in background knowledge may explain why Group 4 gave less accurate explanations during the interviews. Still, their explanations were as good as those from the other three groups, and the only complete explanation of the dissolving of salt was even given by a student in Group 4. This suggests that animation construction can be a powerful learning tool.

During the instruction, the students of Group 3 and 4 made clear that they understood both processes (melting of ice, a solution of salt conducts a current). Two weeks later they seem to have forgotten certain features of the processes. This resulted in incomplete explanations for both processes and alternative explanations for the conductivity of a solution of salt (particles vibrate, electrons are responsible; Table 4).

The students had a mental image of the floating of water on ice, and they knew that a solution of salt conducts a current, but they had not seen the processes itself at the start of the instruction. In order to enforce the link between the macroscopic and the nanoscopic world, the students should *first* see the processes and *then* get instruction in which molecules and ions provide an explanation.

For the first process, they could see a large beaker filled with water and ice. The instructor could point out the fact that ice floats on water. Then, the students should reason that liquid water is denser than ice, which means that there are more water molecules in a mL of liquid water than in a mL of ice. After that, students could be confronted with the model of Figure 1, and discuss whether or not this models is sufficient to explain the floating of ice on water. For the second process, the students could observe that neither pure water (distilled water) nor solid salt conducts a current, but that a solution of salt in water does.

A weak point of this study that the four groups of students came from four different schools and had different backgrounds. Ideally, it would be better if all the students were in the same classroom with the same chemistry teacher, but logistically, is difficult manage four separate groups in one classroom and to keep the groups separated. This can only be done if the students are interviewed directly after the instruction, otherwise they could talk to each other or observe each others' work, which would contaminate the measurement.

A follow up study with four groups from the same school will follow soon to find out if constructing animations give better learning results than only looking at animations and completing assignments about them. The animations of Tasker (Tasker, Chia, Bucat & Sleet, 1996) are better looking and more professional than students' animations made with ChemSense Studio, but there are strong indications that constructing animations gives a better learning effect than just examining them.

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[1] QuickTime and Flash can be downloaded from the Internet at http://www.apple.com/ and www.macromedia.com/ respectively.

[2] Animations: http://vischem.cadre.com.au/.

[3] ChemSense can be downloaded form the Internet at http://chemsense.sri.com/.

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