Multiple Representations in Web-based Learning of Chemistry Concepts

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Abstract

A new chemistry curriculum for secondary schools is currently under construction in the Netherlands, in which chemical knowledge will be embedded in contexts that show applications of chemistry in the society. Several research groups develop such modules and a committee appointed by the Dutch Ministry of Education advises about the chemical content and concepts.
A central issue in chemistry education is the relation between the real, molecular and symbolic world. Skilled chemists switch easily between these worlds, but beginning students do not. They could get better results and will be more able to solve problems if they would make better connections between the three chemical worlds. The University of Twente has developed a series of lessons about the particle model. Included in this instruction material are animations of chemical processes at the molecular level. In the lessons students are supported and stimulated to make connections between the three chemical worlds. Students are shown the importance of new chemical knowledge in society. The mental images and the knowledge schemata of the students are investigated in this research. The students were interviewed before they received instruction, and after they received about half of the instruction. At the end of the instruction they were asked to make a concept map.
It appeared that the links between the real, molecular and symbolic world are not strengthened after the instruction. The students make more links between the real and symbolic world, but hardly connect these world to the molecular world or vice versa. There is still a gap between the students' mental models and scientifically accepted models as represented in animations and illustrations in the instruction. Most students liked the animations in the instruction and mentioned them as strong point. It is therefore surprising that some students could not remember the animations when they were interviewed, whilst others their representations were about the same as the animations. Clearly, the effectiveness of the animations must be enhanced and more research is needed for this.

Introduction

A new chemistry curriculum for secondary schools is currently under construction in the Netherlands. The current curriculum has many drawbacks. It does not give a good view of modern chemistry and applications of chemistry in the society, students don't see why chemistry is useful and there are doubts about the learnability (Pilot & Van Driel, 2001). The new curriculum will be for students aged 15 – 18 years, who follow pre-university and pre-higher vocational education. The proposed structure of the curriculum is modular, with modules of six weeks. The chemical knowledge will then be embedded in a context, which shows applications of chemistry in the society (Bulte et al, 2000). Several research groups develop such teaching modules (Jansen & Kerkstra, 2001a, 2001b; Carelsen et al, 2002; Vermaat. J.H., 2002). A committee appointed by the Dutch Ministry of Education advises about the chemical content (Van Koten et al, 2002).
It is assumed that presenting (chemical) knowledge in a context has several advantages. One advantage is that when students know that they can use the new knowledge outside school, it will enhance their motivation to acquire this knowledge. This will result in better learning (Herron, 1996; Wilson & Cole, 2000).

The macroscopic, nanoscopic and symbolic world in chemistry

A central issue in chemistry education is the relation between the macroscopic, nanoscopic and symbolic world (Nicoll, 2003; Williamson & Abraham, 1995). The macroscopic or phenomenological world is the real world of substances, which can be perceived by the senses. In this world water is a clear liquid and table salt is a white solid. The nanoscopic or molecular world is the world of atoms, molecules and ions. It is sometimes called the microscopic world (Herron, 1996; Nicoll, 2003; Russell et al, 1997), but the word 'microscopic' suggests that atoms, molecules and ions can be seen through a microscope, which is not the case. The word submicroscopic (Nicoll, 2003) is preferable, because it indicates that this world is smaller than the microscopic world. In the nanoscopic world water is a collection of molecules, each consisting of an oxygen atom and two hydrogen atoms, and table salt is a neat lattice of positively charged sodium ions and negatively charged chloride ions. Representations of this world are given in figure 1. Finally, the symbolic world is the world of chemical formulas and equations. In this world water is H_2O and table salt is NaCl.

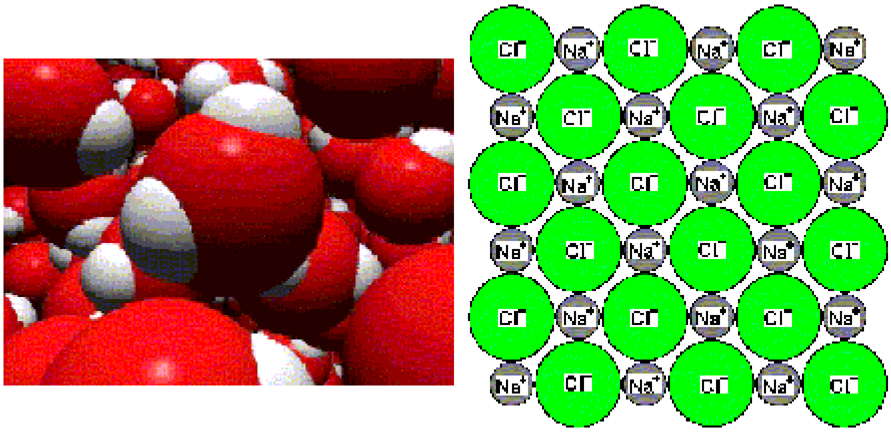

Figure 1 Representations of watermolecules (left) and the ionic lattice of table salt (right).

Experienced chemists switch easily between these three worlds, but novices cannot make easily these connections (Russell et al, 1997). These chemists use a range of signs to create and understand scientific phenomena. They switch between different representations and use them together to solve scientific problems, to foretell certain phenomena and to communicate with other chemists. New students lack both the basic knowledge and the skills to work with different representations. Because of a possible shortcoming of representational knowledge and the skills to use these representations as objects of thought, new students often do not understand scientific symbols (Seel and Winn, 1997; Kozma, 2000). They could get better results and could be more able to solve problems if they would be able to make better connections (Herron, 1996).

Secondary school students often do not understand what happens during a chemical reaction (Johnson, 2000). A chemical reaction is the disappearance of old substances and the appearance of new substances. The explanation of chemical reactions is founded on the concepts of atoms, molecules and ions. In a chemical reaction bonds between atoms and ions are broken and new bonds are formed. Properties are determined by the bonding between atoms and the kind of structures formed. Students have problems to understand the concept of atoms, molecules and ions. They think that these particles are just small pieces of substance and therefore have similar characteristics as the material itself. They perceive atoms and molecules to expand and contract, melt, burn, and so forth. Some students think of atoms as being like cells and believe the nucleus of an atom is about the same as the nucleus of a living cell (De Vos, 1985; Harrison and Treagust 1996; Vollebregt et al, 1999). Furthermore, it is supposed that students cannot associate the concepts of atoms and molecules with knowledge they already have acquired (Tsaparlis, 2000).

Beginning chemistry students have to learn about symbols or symbolic models and they have to make connections between symbols, molecular models and the real world. Herron and Greenbow (1986) found that many students fail to make strong connections between the symbolic signs (chemical formulas) and the physical reality that these signs are representing. Students treat chemical formulas as mathematical puzzles without understanding the chemistry that is underlying these symbols (Kozma, 2000; Marais and Jordaan, 2000).

Atoms, molecules and ions are to small to be seen, so chemists must work with models or representations. The computer offers new opportunities for teaching chemistry, for it is possible to visualize 'molecules in action' at a computer screen. Motion is an essential feature of molecules during a chemical reaction, and computers make it possible to show this in an animation. Animations at the particle level are available for the dissolution of salt in water, for the melting of ice and the evaporation of water, for chemical equilibriums, for precipitation reactions, and many more. Students can manipulate molecular models at the computer when they use the plug-in Chime (Dorland, 2002). With programs like ChemSense they can make their own animations (Schank, 2000). It is supposed that students will learn the particle theory better when they use visualization. Furthermore, visualization arouses interest and students develop a more positive attitude for chemistry (Wu, 2001). Animation gives an even better idea how particles behave, so it can be expected that the use of animations will get better results.

Instruction material

The University of Twente has developed a series of lessons, called Lespakket "Nierdialyse" [teaching packet "Hemodialysis"], about the particle model (Vermaat, 2002). In these lessons students are supported and stimulated to make connections between the three chemical worlds: macroscopic, nanoscopic and symbolic. Students are furthermore shown that chemical knowledge is required for explaining and understanding the proces of hemodialysis. Moreover, a goal of this series of lessons is to teach the students chemical concepts.

In the series of lessons, many assignments are presented in which the students have to make connections between the three chemical worlds. For example, students are shown an animation of the melting of ice, in combination with a photo of a glass of water and ice. The students have to explain why ice floats on water. For a good understanding they have to use the nanoscopic world that is presented in the animation. After this assignment the students have to give adequate descriptions of the melting of ice in the macroscopic, nanoscopic and symbolic world. The last description is the equation H_2O (s) $\rightarrow$ H_2O (l), with the explanation that H_2O (s) is solid water (ice) and H_2O (l) is liquid water. In another example of a task students discover that solutions of salts conduct electrical current, while solutions of molecular substances do not. The explanation is that an electrical current is a movement of charge. In a solid salt the ions, charged particles, cannot move. However, in a salt solution the ions can move. The students are shown an animation of the dissolution of table salt in water in the nanoscopic world and animations of a hydrated sodium and chloride ion.

The context of the series of lessons is hemodialysis. A story is told about a 15-year-old girl who has to go three times a week to a hospital for dialysis as she suffers from a kidney disease. She is curious to find out what exactly happens in an artificial kidney and the students are asked to write an information leaflet for this girl. In order to do so, the students have to learn about molecular and ionic substances (salts) and atoms, molecules and ions and explain these concepts to their peers.

Among the chemical concepts the students are taught are: molecular and ionic substances, molecular and ionic lattice, atomic and ionic bonding, Van der Waals bonding, dipole attraction, hydrogen bonds, polar and apolar substances, atomic model of Rutherford, atomic and ionic radius, structural formula, dissolving of salts and molecular substances and precipitation reactions.

Research Questions

During regular lessons the year before the students were presented a general molecular model of a solid, a liquid and a gas (figure 2). The molecules in a solid stay at their place, while the molecules in a liquid move at random. In a gas the molecules also move at random, the distance between the molecules is much larger then in a liquid, and there is no attraction between the molecules. This simple model explains why one can put a solid object in a liquid, but it does not explain why ice floats on water. It was assumed that the students have a more sophisticated image of ice and water after the instruction. Because the students were not instructed about salts and ions the year before, it was assumed that before instruction they would have a 'molecular' image of table salt (NaCl). This means that they will think that table salt consists NaCl-'molecules' instead of Na^+- and Cl^--ions. After the instruction they received during this research, they should have more scientifically accepted images.

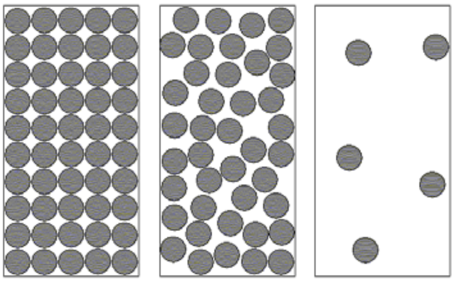

Figure 2 The molecular model of a solid (left), a liquid (middle), and a gas (right) that was taught to the students before this reasearch.

While the students are learning the new concepts, they will integrate these concepts in their knowledge schemata (Herron, 1996; Marzano, 1992). It is therefore interesting to investigate how the students organize their knowledge. Concept maps (Novak & Gowin, 1984), made by the students after instruction, give an indication for this.
The main research questions of this investigation were:

1. Is there a change in the mental images of the students during instruction to models that are accepted by the scientific community?
2. What do the knowledge schemata of the students look like and do students develop connections between the three chemical worlds?

Method

Participants

One class of ten 10th grade pre-university students participated in this research. The year before these students had followed a chemistry course during the whole school year. In this the concepts molecule and atom had been taught, but not the concept ion.
For this research the students followed the series of lessons for two hours a week during seven weeks. Outside class they worked one hour a week at this project, at home or at school. Each student received a cd-rom with the lessons on it, and they were able to visit the website with the same lessons. Some lessons were planned for experiments in the laboratory. Two students get special soccer training. They could attend only one lesson a week and missed the laboratory experiments.

Materials

Included in the instruction material (Vermaat, 2002) are animations at the nanoscopic level of liquid water, ice, melting of ice, dissolving of table salt, a hydrated sodium and chlorine ion, laboratory experiments about the conducting of solutions of salts and molecular substances, and assignments about these issues.

A few months before this research a group of twelve students had tested the series of lessons. This group consisted of four 10th grade and eight 9th grade pre-university students. The 9th students had more or less the same background in chemistry teaching as the students who participated in this research. The 10th students knew considerably more. Several modifications had been made after these students had tested the series of lessons.

Instruments

All the students were interviewed two times. These interviews were semi-structured, the interviewer used the same open-ended questions for each student (table 1 and 2). The interviewer actually asked the students to draw the particles in water and table salt and the way these particles are linked together. These drawings give a good image of the mental models the students have and how the models develop during the instruction.
In the interviews the students were asked to make 'webs' of the concepts water and table salt. For this webs the students write the central concept (water or table salt) down, and after that they write down the concepts they associate with the central concept. These webs give an indication about the way the students organize their knowledge. Furthermore the students were shown an example of a concept map (Novak & Gowin, 1984). After they had studied this map, they were given eleven little papers with a concept printed at each paper. They were asked to make their own concept map with these concepts. The concepts are listed in table 3. The students did not have to use all the given concepts, and they could add concepts as they thought they were missing.

Table 1 The list of questions for the first interview.

1.	(A glass of water was shown.) What do you think if you see water?
2.	What is your picture of a collection of 'water particles' if the water is liquid? And if it is solid? And if it is a gas?
3.	(Some table salt was shown.) This is salt; can you describe this substance in words?
4.	How do you picture that the 'salt particles' are linked together? It is possible to melt salt if it is heated. How do you think the 'salt particles' look like if the salt is molten?

Table 2 The list of questions for the second interview.

1.	Here is a classification scheme of substances. Substances can be classified in pure substances and mixtures. Pure substances are classified in elements and compounds. This is an international agreement among chemists. Do you understand this classification? (First a classification scheme of substances was shown. This was done because some students had the misconception that compounds are mixtures. This misconception is widespread among beginning students in chemistry (Taber, 2002).
2.	I would like to talk about the pure substance water. If you think about water in a chemically way, what is it you think about?
3.	How do you picture a collection of water molecules in solid water, thus in ice? In the instruction you have seen an animation and a model of ice. Are there any differences between the drawing you made and the animation or model? Can you explain the differences?
4.	Another pure substance is table salt. If you think about table salt in a chemically way, what is it you think about?
5.	How do you picture the particles in salt are connected to each other in solid salt?
6.	What are the building blocks of salts? What kind of bonding is between these particles?

Table 3 The eleven concepts for the concept maps

atomic bonding	compounds	dissolving
ionic compounds or salts	molecules	ionic bonding
ionic lattice	molecular compounds	molecular bonding
atoms	ions	

Procedure

The interviews took place before the start of the series of lessons, and after the students had received about half of the instruction. At this point they were taught the explanation of the floating of ice, what salts are and that salts consist of ions, not of molecules. After instruction the students were asked to make the concept maps.

Analysis

All the interviews were taped and the drawings and the concept maps were scanned. The results of all interviews were written down. After that the mental images of the students, which are represented in their drawings, were classified. The webs and concept maps were analysed to see if the students had developed a more 'chemical' knowledge schema, and if the developed connections between the three chemical worlds.

Results

Model of water

In the first series of interviews, students were asked to make drawings of the water molecules in ice, liquid water and water vapor. At that moment they did not know anything about hydrogen bonding and the crystalline structure of ice. Six students made a drawing in which a water molecule is represented by a sphere (figure 3, left part). Three students made drawings in which each water molecule consists of three spheres which represent the oxygen and hydrogen atoms (figure 3, right part). One of these students could only make a drawing of the molecules in liquid water. The tenth student had no idea how to make drawings of ice, liquid water and water vapor.
In each section of figure 3 the upper drawing is that of molecules in ice, the one in the middle is a drawing of the molecules in liquid water and the lowest drawing is one of the molecules in water vapor. These pictures are in accordance with those of figure 2.

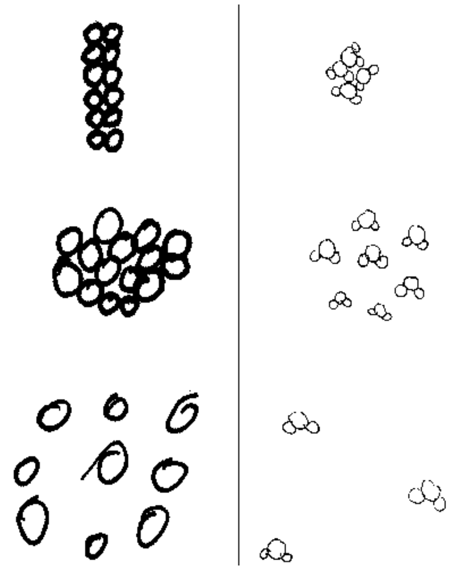

Figure 3 Drawings of the molecules in ice, liquid water and water vapor by the students during the first series of interviews.

In the second series of interviews the students were asked to make a drawing of the molecules in ice. At that moment they had received instruction, which included a model of ice and an animation of the melting of ice at the nanoscopic level. In this instruction they had to explain why ice floats on water and does not sink. The 'old' molecular image of ice and liquid water as drawn in figure 2 does not give an explanation for this. The explanation is that in ice the molecules are in a regular lattice with more space between the molecules than in liquid water. Furthermore, the students were taught the concepts dipole and hydrogen bonding.

Six students still made drawing that are like the models of figure 2. Among these students is the one who could not make a drawing in the first interview. Five students sketched circles in a regular lattice in which each circle represent a water molecule. The sixth student draw water molecules that consist of two hydrogen and one oxygen atom.

Four students knew there was something 'strange' about the way molecules in ice are arranged. One of these mentioned and sketched the hydrogen bonding between the water molecules (figure 4, extreme left). Another student first sketched the 'old' model of ice, but made a correction and sketched a hydrogen bonding between two water molecules. For this model a structural formula was used (figure 4, middle left).

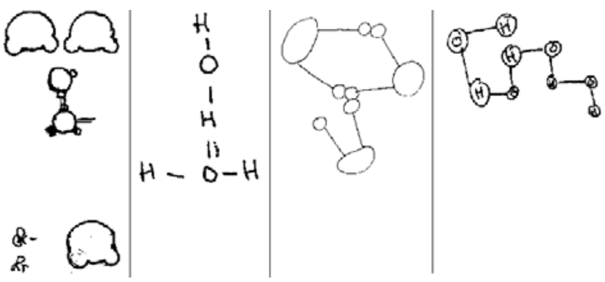

Figure 4 Drawings of the molecules in ice after instruction.

Eight students did not remember the animation or the model of ice and the melting of ice. Two students thought that the animation was about the same as their pictures.

Model of table salt

As was expected, all students thought in the first series of interviews that table salt consists of 'molecules' NaCl (figure 5). All students thought that the models of solid, liquid and gasiform table salt are the same as the models of water, and are in accordance with figure 3.

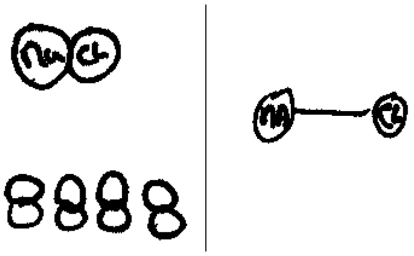

Figure 5 The students' models of table salt (sodium chloride, NaCl) as drawn during the first series of interviews.

After the first series of interviews the students received instruction about salts as ionic substances. Among others, they were shown ionic models of table salt, discovered in the laboratory that solutions of diverse salt in water conduct an electrical current, while solutions of molecular substances don't, and were shown an animation of hydrated ions and the solution of table salt at the nanoscopic level. It was emphasized that there is no such thing as a sodium chloride molecule, and the smallest particles of salts are ions. After his instruction the students were asked the following question in the second series of interviews: "How do you picture the particles in salt are connected to each other in solid salt?"
Only one student sketched an ionic lattice (figure 6, right). Seven students still had a molecular image as can be seen in figure 6. Each sphere in the upper left part of this figure represents a NaCl-'molecule'. Two students had no mental image of the particles in table salt.

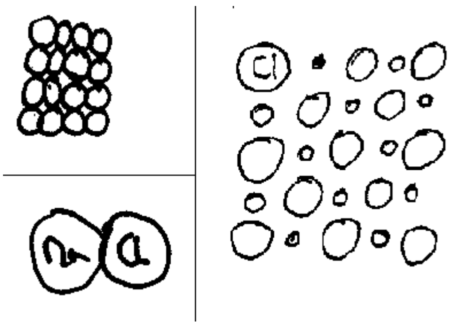

Figure 6 Students' immages of table salt after instruction about the ionic structure of salts.

When asked what was the attractive bonding between the particles, one student answered: "I think with dipole bonding. They attract each other with London forces." Another student said that electrons are responsible for the attractive forces between molecules. A third student thought the attractive force in this model is de Van der Waals force. The other students did not know what the attractive bonding is.

Knowledge schemata

In the first and second series of interviews the students were asked to make 'webs' of the concepts water and table salt. For this webs the students write the central concept (water or

table salt) down, and after that they write down the concepts they associate with the central concept.
During the first series of interviews the concept water was mostly associated with concepts from everyday life as swimming, sea, tap, thirst, liquid, rain. Only two students wrote down the formula of water, H_2O. In the second series of interviews the students were asked to think more 'chemically' about water. All the students mentioned the formule H_2O. Six students mentioned the three phases of water: solid, liquid and water vapor.
The results for the webs of table salt are comparable. In the first session only one student mentioned the formula, in the second session all the students mentioned the formula NaCl for table salt. Moreover, three students associated the concept salt with the concept 'metal + non-metal'. The particles of most salts are positively charged metal ions and negatively charged non-metal ions.
An example of the webs of two students can be seen in figure 7 and 8. It is obvious that the student who made the webs in the right part of both figures associate many more concepts linked with the concepts water and salt than does the other student. The first student has adapted much chemical information.

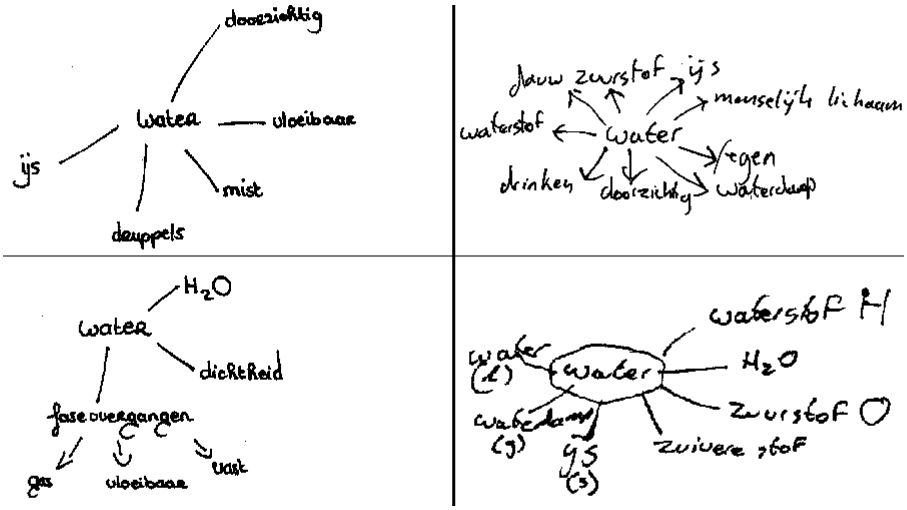

Figure 7 Webs for water by two students made during the first interview (top) and the second interview (bottom).
Translation left side of figure: doorzichtig = transparent; vloeibaar = liquid, mist = fog, druppels = droplets; ijs = ice; dichtheid = density; faseovergangen = phase transitions; gas = gas; vast = solid.
Translation right side of figure: dauw = dew; zuurstof = oxygen; ijs = ice; menselijk lichaam = human body; regen = rain; waterdamp = water vapor; doorzichtig = transparent; drinken = drink; waterstof = hydrogen; zuivere stof = pure substance.

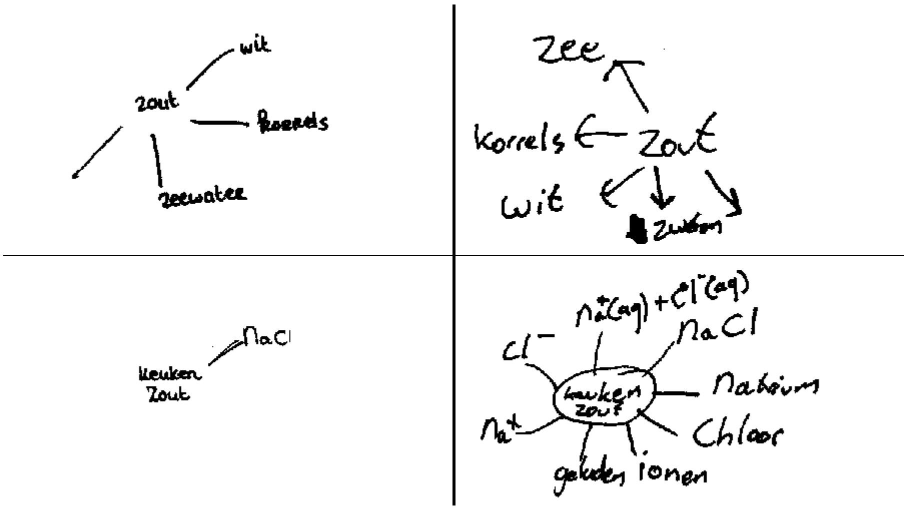

Figure 8 Webs for table salt by two students made during the first interview (top) and the second interview (bottom). These are the same students who made the webs of figure 7.
Translation left side of figure: zout = salt; wit = white; korrels = grains; zeewater = seawater; keukenzout = table salt.
Translation of right side of figure: zout = salt; zee = sea; zweten = to sweat; wit = white; korrels = grains; keukenzout = table salt; natrium = sodium; chloor = chlorine; ionen = ions; geladen = charged.

A concept map of the concepts from table 3 made by an experienced chemist can be like the one in figure 9. Under the concept ‘molecular bonding’ this chemist would probably add the concept ‘molecular lattice’. Is is also possible that the chemist would link ‘dissolving’ to molecular compounds as well (the molecular compound sugar will dissolve in water). Probably the chemist will put many additional concepts in such a map.
Five students made concept maps that looked like the map of figure 14. Of these, one classified $FeSO_4 \cdot 7\ H_2O$ and $Na_2CO_3 \cdot 10\ H_2O$ as molecular compounds in stead as salts.
Two students made no links between the molecular and ionic compounds.
Two other student made links, but not the correct links. One of these students classified molecular compounds in compounds, mixtures, elements, metals and ionic compounds. The other linked the concept molecular bonding, ionic bonding and atomic bonding to the central concept Van der Waals bonding. These two students added new concepts to the map as hydrogen bonding, metals and mixtures, and Van der Waals bonding.
The tenth student was ill and did not made concept maps.

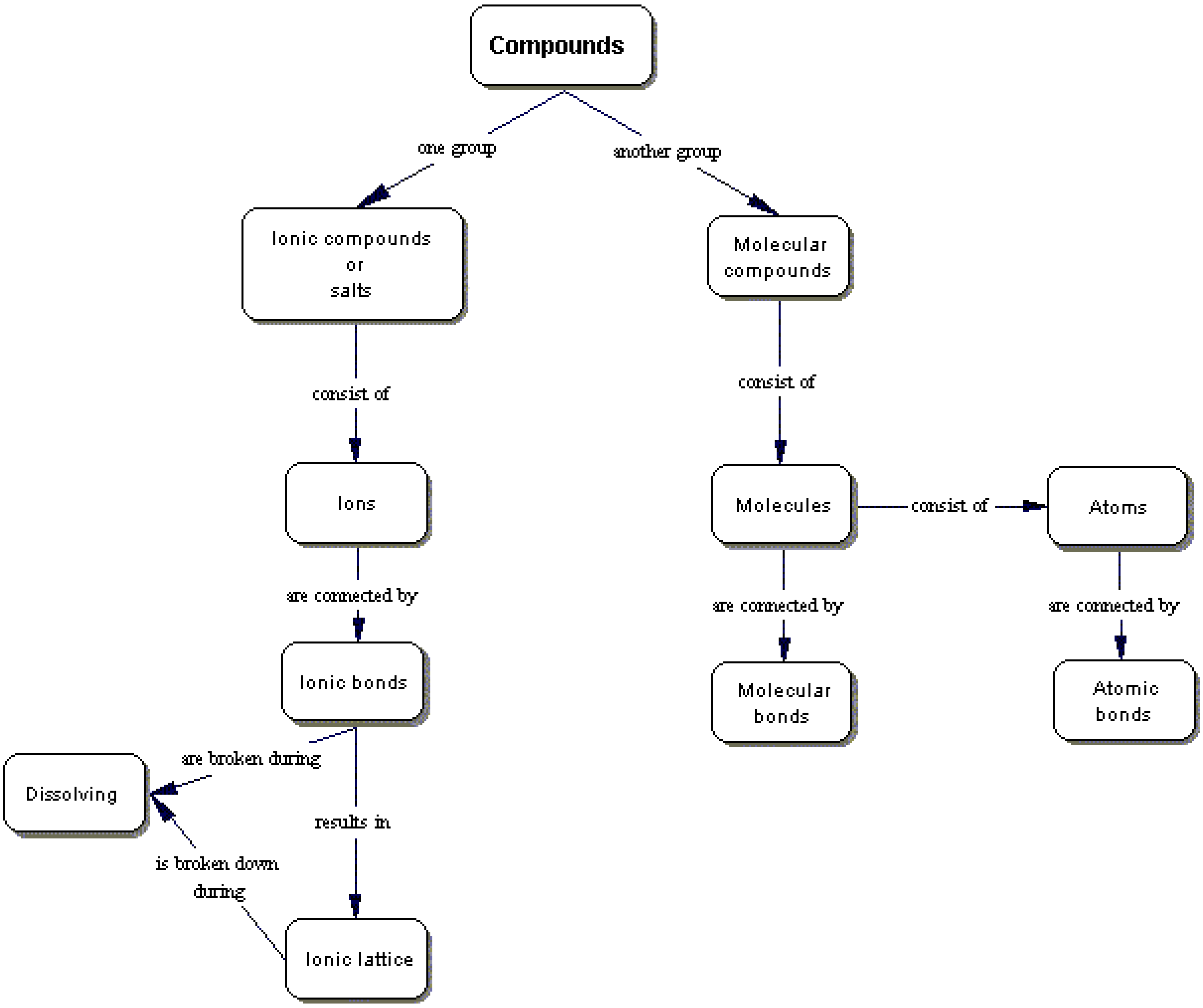

Figure 9 Concept map of the concepts in table 3 as can be made by an experienced chemist.

Discussion

In the instruction the students were asked to explain why ice floats on water. They were shown an animation, in which an explanation is given. Nonetheless, the students hold on to their old mental image of the distribution of molecules in ice, even if this is not sufficient to explain the phenomenon that ice floats on water. Some students knew there was something ‘strange’ about the arrangement of the water molecules in ice, but they did not know what is was. None of the students linked the macroscopic world up with the arrangement of the water molecules in ice and water. Because eight students could not remember the animation or the model of ice and two students thought their images was about the same as the animation, this series of lessons must be improved.

As was expected, all students had a molecular image of table salt before they received instruction. They all thought that table salt consisted of NaCl-‘molecules’ analogous to water molecules. After the instruction most students still had this naïve conception. In an animation the students saw how the ions were removed one by one from the ionic lattice, and not in pairs. Moreover, the students have seen animations of hydrated sodium and chloride ions. In this case the students made no strong connections between the nanoscopic and macroscopic world. Just looking at the animations is not enough.

During instruction the students developed 'chemical' knowledge schemata. In the first series of interviews these concepts were linked to concepts of everyday life, in the second series of interviews there appeared more chemical concepts as the building blocks of the substances water and salt. They mentioned the formulas of water and table salt (H_2O and NaCl) when asked to make webs of these concepts.
After instruction five students made concept maps that were analogous to a map made by an experienced chemist. This suggests that their knowledge schemata are like that of skilled chemists, although the knowledge schemata of the latter will be more extended. Two students made no links between molecular compound and salts, they did not recognize that these were different groups of compounds. Two other students made wrong links between concepts. These students knew many concepts, but could not arrange these meaningfully in their concept maps. The students wrote the formulas of some compounds (symbolic world) in their maps, but no representations of the nanoscopic world.

When asked their opinion about the instruction, some students responded that they preferred a book to web-based learning. It is tiring to look at a computer screen for long times and it is less tiring to read a book. Others preferred the computer because of its interactivity and the animations. There were mixed feelings about the context. Most students of the group who tested the instruction before this study liked the context, because they could see where chemical knowledge is used in daily life. The students who participated in this research were less positive, although about half of the students liked the context. For this students the lessons were school routine. The first group of students were volunteers who came to the University of Twente especially to test the instruction. For them it was an adventure to leave the classroom and go to a university, so their attitude was more positive from the beginning.

Most students made more connections between the macroscopic and the symbolic world as can be concluded form the 'webs' made of the concepts water and table salt. The links to the nanoscopic world are hardly made by these students. Probably the instruction material requires more assignments in which the students have to make connections between the three chemical worlds. It is clear that the links between the macroscopic, nanoscopic and symbolic worlds are not strong enough after the instruction given by this web-based series of lessons. The students make more links between the macroscopic and symbolic world, but hardly connect these world to the nanoscopic world or vice versa. There is still a gap between the students' mental models and scientifically accepted models as represented in animations and illustrations in the instruction. Most students liked the animations and mentioned them as a strong point of this web-based instruction. It is therefore surprising that the students could not remember the animations when they were interviewed, or thought their representations were about the same as the animations. Clearly, the effectiveness of the animations must be enhanced.
The interesting question is when and how animations will promote learning (Mayer & Moreno, 2002). Motion is the special quality of animations and therefore animations will promote learning of dynamic processes (Large, 1996). Chemical processes are examples of such processes, so animation can be a powerful tool in chemistry education, but more research is needed to improve the effectiveness of this tool.

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