Teachers' solutions: a learning study about solution chemistry in Grade 8

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Abstract

Purpose – The purpose of this paper is to describe the collective exploration, process and knowledge production made in a learning study about solution chemistry.

Design/methodology/approach – Secondary school teachers conducted a learning study with variation theory as a guiding principle, supervised by a researcher. The relationship between teaching and learning was analyzed and evaluated in a learning study cycle of three lessons.

Findings – Critical aspects when teaching solution chemistry were identified, as well as enacted patterns of variation that significantly improved students' learning. Examples of critical aspects were the particulate character of matter, especially the feature of "empty space" between particles, the connection between macroscopic phenomenon and sub-microscopic explanations and the difference between answers with everyday language and scientific language.

Practical implications – The paper suggests that teachers in a learning study can produce new knowledge as well as use earlier research results when creating teaching activities that can improve their own practical work and students' learning.

Originality/value – The study represents an example of research with the aim to improve teachers' practice by generating knowledge in connection with teachers' professional tasks.

Keywords Teachers, Secondary schools, Learning studies, Variation theory, Solution chemistry, Matter, Science teaching, Teacher learning

Paper type Case study

Introduction

In the research project "Teachers' common knowledge development – how teachers' professional learning develops as a shared scientific practice" founded by the Swedish Research Council we, six secondary school science teachers, conducted three learning studies supervised by a researcher. The overall research questions concerned the character of the knowledge teachers achieve and develop while participating in learning studies. In the learning studies, we studied our students' learning and how it was related to our own teaching while the researcher studied our learning and knowledge production during the process. This paper reports the results of the third, and last, learning study in the project.

We are all experienced science teachers with limited experience with educational research. Our school has about 300 students in grades 7-9, and about 60 students in

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three classes participated in the learning studies, the first one starting in their seventh school year. The object of learning in the first study focussed on the concept of matter, and the second study dealt with photosynthesis, with a focus on the role of carbon dioxide. Findings and experiences from the first two studies made it clear that the concept of matter is crucial for students' understanding of a whole range of science phenomena and processes. We adopted chemical solutions as the object of learning in the third learning study; solution chemistry was considered appropriate content when the aim is to increase students' understanding of the particulate character of matter. Another reason for choosing this subject was the fact that solution chemistry had been dealt with already in grade 7, but at that time without acknowledging the experiences that had been achieved during the earlier learning studies. In this paper, findings made in the third learning study about solution chemistry will be presented.

The study: design, data collection and analysis

The learning study was conducted within the framework of variation theory (Marton and Tsui, 2004) and in the cyclic way that Holmqvist *et al.* (2008), Marton and Lo (2007), describe. It was carried out through collaboration between the teachers and the supervising researcher. The study took place when the students were in eighth grade, and lasted one semester. It included five meetings that lasted three to four hours each, three lessons and student tests. All six of us participated in the meetings connected to the study, and in excerpts from the discussions, we are called with our first name. In the excerpts from the lessons we are called teacher 1, 2 and 3, depending on whether we were teaching the first, second or third lesson. The reason for this was that we wanted to point out the quality of the lesson, not the individual teacher. The design can be described as follows:

(1) The object of learning was determined and the student pre-test designed (Meeting 1).

(2) Teacher 1, 2 and 3 carried out the pre-test in their classes.

(3) The result of the test was discussed and analyzed, and a lesson plan was constructed that was informed by the result of the pre-test, with the object of learning as a point of departure. A post-test was designed, almost similar to the pre-test (Meeting 2).

(4) Teacher 1 carried out the lesson in the first class. The lesson was video recorded by the researcher. The teacher gave the post-test to the students a few days later.

(5) The post-test and the video recorded lesson were analyzed, and the lesson plan was once again revised (Meeting 3).

(6) Teacher 2 carried out the revised lesson with a new group of students and a post-test was done.

(7) The post-test and the lesson were analyzed, and the lesson plan revised once more (Meeting 4).

(8) Teacher 3 carried out the last lesson in her class as well as a post-test.

(9) After analysis, overall conclusions of the study were drawn (Meeting 5).

Data were collected during the whole process. In the learning study, written student tests and supplementary interviews carried out by the teachers with select students contributed data on students' learning. Combined with the video recorded lessons, this made it possible to analyze the relationship between teaching and learning, that is – what was intended, what was enacted and what was experienced. Further, the discussions at the meetings were tape recorded, transcribed and analyzed by the researcher, making it possible to get an idea of how the process developed and how findings were made through the discussions.

Variation theory was used as a guiding principle throughout the three learning studies. We had been introduced to the theory in the preceding learning studies through lectures and articles. In the first cycle, we were unfamiliar with the theory. In the third cycle, it had become more of a "lived" theory – a natural part of how student tests were constructed and analyzed and how lessons were planned. The theory was used as a tool throughout the analysis of the data. The student tests were analyzed on a collective level, revealing different ways of understanding the object of learning in a particular group of students. The supplementary interviews with some of the students then validated the categories found. Even more important for the reliability of the test results were the independent analyses made by the researcher and the teachers. At the follow-up meetings, the results of the analyses made by the researcher and us were compared and found to match. Conscious attention was paid to the opportunities for learning that was offered during the lessons; these were compared with the results of the students' learning. A frequently question asked was: What was possible for the students to discern and learn, and what was not?

Adamson and Walker (2011) describe and analyze what they call "messy collaboration," when teachers and researchers work together in a learning study. The "messiness" includes "potential tensions such as outsider versus insider perspectives; academic versus grounded knowledge; unclear hierarchical structures; and diverse and conflicting agendas" (Adamson and Walker, 2011, p. 35). The partnerships and roles of the participants in the two preceding learning studies could also be described using these characteristics, especially in the first study. Even if the researcher had a background as a secondary school science teacher, which helped her understand the perspectives of teachers better, her role was that of the academic researcher, while we were the grounded practitioners. In the first study, the researcher acted as an "expert teacher educator," lecturing us about variation theory and results from science education research. As we in the beginning mostly focussed on general teaching actions and issues, the researcher used her special competence in supervision to focus on the object of learning and its critical features. However, in the third study described in this paper, the roles were changed. We now mastered the theory, making it possible for us to share a common ground with the researcher, as well as with each other. Anna's comment "Our way to talk with each other is changed, now we talk about the same things!" is a good illustration. In the first learning study, planning and revising the lesson plans were a "messy collaboration" (Adamson and Walker, 2011), but as the three studies progressed we changed our way of offering the students the object of learning from a more general way to a much more specific content-related way, a result supported by Holmqvist (2011) who also conducted three learning studies during three semesters.

The analysis of the student tests developed throughout the three studies: the result categories found changed from being more or less quantitative, "straggly" and non-corresponding in the first study, to distinct, qualitative and shared categories in the third study. The roles of the participants changed over time: we became more independent and took on a greater responsibility, while the researcher assumed a more withdrawn position. The same development was found by Vikström (2005) in a collaborative school project between a group of teachers and an academic researcher that lasted three years. A conclusion might be that one learning study can be a "messy collaboration," while three or more studies conducted with the same group of participants can become a tidy and rewarding one. It takes time to "create speakers of multiple points of view but with sufficient expertise to be relevant" (Adamson and Walker, 2011, p. 36, with reference to Kelly).

The object of learning: solution chemistry

Concepts such as dissolution and the particulate nature of matter are fundamental to learning chemistry (Abraham *et al.*, 1992). Students' ideas about these concepts have been the focus of several researchers over the past three decades. Research has shown that students often regard matter as static, continuous and non-particulate, in contrast to the scientific atomistic and dynamic view (see e.g. Driver *et al.*, 1994).

In a review of solution chemistry studies, Calýk *et al.* (2005) summarizes findings about students' understanding of solutions. The review claims, for example, that students often pay the most attention to mechanical events, such as stirring; that everyday language is preferred over scientific jargon; that students confuse solution chemistry with non-related concepts; and that students lack sub-microscopic explanations for macroscopic observations of the phenomena.

Results from science education research about the concept of matter were presented to us in the first two learning studies and influenced how the object of learning was formulated and defined in the third cycle. This knowledge, combined with conclusions drawn from the first and the second learning study, led to the following definition of the object of learning in the third study:

> The students shall develop the ability to describe solutions at a sub-microscopic level as a homogenous mixture of particles. They shall also develop the ability to use the rule "like dissolves like" when separating substances that are soluble in water from those who are not.

An object of learning has two aspects, the direct and the indirect object of learning. The direct object of learning refers to the content as such, and the indirect object of learning is the capability that we expect the students to develop (Marton and Pang, 2006). We have expressed our object of learning at a level that includes both the direct and the indirect object of learning, that is what the learner is expected to be able to do with the content.

The core idea of variation theory is that variation is a prerequisite for discernment and that discernment is a prerequisite for learning. To learn certain things in certain ways means that the learner must become aware of certain critical aspects of the object of learning and discern them simultaneously (Marton and Booth, 1997; Marton and Tsui, 2004; Runesson, 2006; Marton and Pang, 2006). Discernment demands contrast; opportunities to experience differences are crucial in teaching and learning science. The general law of solubility states that "like dissolves like," and already from the first meeting, some patterns of variation were presumed to be important to reach that general understanding. It was stated that it was important to discern the difference between substances that can be dissolved in water and ones that dissolve in organic solvents, as well as similarities between the substances in each group. The patterns that were observed also included the difference between homogenous solutions and heterogeneous mixtures, as well as the fact that solids can be dissolved in liquids, liquids in liquids and gases in liquids.

The students pre-understanding and limiting the object of learning

The Swedish syllabi describe the concept of matter as central content in school science. In order to get a passing grade in ninth grade chemistry, the students must acquire an ability to use chemical concepts in discussions about chemical processes in nature, in the human body and in society. Therefore, we wanted the concept of solubility in these different contexts to be part of the object of learning. The result of the pre-test, however, showed that it was necessary to limit the object of learning and focus on a few critical aspects that had to be discerned by the students in order to reach the overall aim of the study: a dynamic and particulate view of matter.

Pre-test question 1 was "Which of these substances are soluble in water?" The students had to circle the correct substances among several examples given. The result showed that about 50 percent of the students grasped the concept while the other half seemed uncertain. One-fourth of the students only circled solid substances, like salt and sugar, as soluble in water. The same finding has been made by, among others, Prieto *et al.* (1989).

The second question was open-ended: "How to determine if something is dissolved?" The aim was to investigate how the students observed and described the process at the macroscopic level. However, it was concluded that the question was not formulated correctly, as almost all of the students answered something like "by making an experiment." It was decided to replace this question with a more productive one.

The third part of the pre-test contributed the most to the knowledge of the students pre-understanding: "Explain, as well as you can, what a solution is," but it was also the most difficult to analyze. The varying answers given by the students offered opportunities for us to discuss qualitative differences between the answers, and gave valuable information for the lesson plan. A total of 15 percent of the students did not answer the question at all, or answered in a way that was found irrelevant. More than two-thirds of the students described solutions at the macroscopic level using everyday language. No one used the word "melt" instead of "dissolve," probably due to earlier learning studies. In the first learning study about matter, students used the word "melt" as synonymous to "dissolve," and had difficulty understanding the difference between the two phenomena. We then explained the students' misconception as a result of the everyday experience students get when sugar is said to "melt" in hot tea or coffee. Findings of the same kind are presented in Calýk *et al.* (2005).

Only four students out of 60 described the solution concept in a way that could be categorized as at least partly sub-microscopic and by using chemistry terms. This result can be compared with studies made by Prieto *et al.* (1989) and Ebenezer and Ericksson (1996), which also showed that few students at this age made references to some kind of particle model.

The pre-test also included questions about solutions in nature, in the human body and in society, but were excluded for the reasons mentioned above.

The lesson plan

The pre-test, together with experiences gained from the two first learning studies, provided us with important information for planning the lesson. The following transcript from Meeting 2 illustrates what a discussion leading up to the planning of the lesson could look like:

Peter: What are "particles"? Can we use another word?

Kerstin: Molecules and ions.

Peter: Equidistant.

Kerstin: Spread in the whole volume.

Researcher: That is, "homogenous".

Peter: Is that possible to show somehow?

Kerstin: Remember, we had problems with our models in learning study 1; they didn't work out as we hoped.

Gunilla: But we have to use models, or they will not understand.

Monica: We have to point out "equally spread".

Researcher: And liquids in liquids.

Peter: First we have to show the difference between soluble and not soluble, then what "homogenous" means.

Researcher: Yes, it is like a two-step rocket.

Kerstin: They believe sugar and salt are always soluble, but they are not.

Gunilla: Not in oil, and not in alcohol, but alcohol is not a good example since it is a little bit "in between," isn't it? And we want sharp contrasts, don't we?

The transcript also shows how we deepen our own understanding of the phenomena when we explore the critical aspects further:

Kerstin: How can we think about this? We think water divides salt into "ion particles," but if we pour alcohol into water, is water then dividing the alcohol, or [...]? Can we say that water separates alcohol molecules? And what if that solution is saturated, what does that mean? Can a solution of water and alcohol be saturated?

Parviz: Water and carbonic acid, what about that?

Kerstin: It can be saturated, but then carbon dioxide leaves the solution, just as saturated hydrochloride [...]

Peter: Maybe we should avoid examples of dissolution of gases in this lesson; it's too complicated.

During the discussions, it was concluded that certain efforts had to be made to make the sub-microscopic level possible to discern for students, as chemistry generally relies on a theoretical model that requires students to think at this level. When dealing with solution chemistry in seventh grade, the focus had been on the conditions that influenced the dissolution process, such as stirring, pulverizing and temperature – something we now realized did not support the students' comprehension at the molecular level. It was also stated that the particulate character of water and other solvents should be taken into account, and that examples should be given of liquids dissolving in other liquids. However, since the lesson was only 45 minutes, it was decided not to deal with the dissolution of gases.

The meaning of "equals dissolve equals" was intensely discussed: understanding the rule involves concepts the students were unfamiliar with, such as ions and polar/non-polar molecules:

Peter: Those "charges" are a problem.

Monica: At least we can show that the molecules look different. It will help them a bit further.

Peter: If we talk about charged particles, we also have to talk about the ones that are not charged.

Kerstin: If something is "equal," there is something specific that is equal, for example that the polar ones are small and the non-polar ones are bigger.

Monica: They don't fit together.

Anna: We can say "small, charged" and "big, non-charged" and if someone asks a question we can draw a water molecule and explain it further.

When watching ourselves in the video recorded lessons in learning study 1 and 2, we had also drawn concrete and practical conclusions about teaching and ways of making critical aspects plain and distinct – such as how we used the whiteboard, and how we performed demonstrations and experiments in front of students. For example, it was found that patterns of variation can be pointed out by using different colors and structures when taking notes on the whiteboard; by making experiments in a certain order; and by sorting beakers in certain groups at the desk in the front. Even more important was the experience we had gained about how our interaction and dialogue with students could make critical aspects of the object of learning visible and in-focus, but also the opposite; critical aspects could be hidden in a blur when the dialogue strayed away from those aspects.

After Meeting 2, the lesson plan was agreed upon and outlined in writing. The plan is shown below, in brief:

LESSON PLAN:

(1) Soluble/not soluble
Demonstrate examples using different substances. Write the results on the board, soluble pairs at the left and non-soluble pairs on the right. Put the beakers on the left and right side of the desk in the same order.
Substances to combine: water, cooking oil, salt, sugar, copper sulfate, gasoline, ethanol, paraffin oil, sand, powdered sulfur and coal.
Important: liquids in liquids.
Compare the groups. Point out the difference between the two groups and the definition of a solution. Explain homogenous and heterogeneous on a macroscopic level, as well as on a microscopic level, using molecule models.
Important: nothing has disappeared, but is equally spread.

(2) Water compared to organic solvents
Ask students how they clean their hands to remove motor oil, for example. Why does not water work?
Point out similarities between water and ethanol, for example, as well as similarities between oil and gasoline. Show differences between the two: small polar molecules vs large, non-polar molecules. Explain the general rule of "equals dissolve equals," while mentioning the substances and pairs listed above.

Result of the first lesson

The first lesson and post-test were carried out and the results were discussed at Meeting 3. First it was concluded that significant improvement had been made. The answers to question 1, "Circle the substances that are soluble in water," showed that only three of the students remained uncertain (compared to eight in the pre-test), and that 18 out of 21 students showed good insight with less than two wrong answers. What was noteworthy is that no one circled only solid substances (compared to one-fourth in the pre-test); a result that remained unchanged during all three cycles of the study. Question 2 on the post-test was new: "Circle the pairs where the substances are soluble in each other," followed by examples such as "oil-water," "oil-gasoline" and others. More than two-thirds of students answered this question correctly.

It was concluded that students' experiences from this part of the object of learning was quite satisfying. This was seen as a result of the efforts to show many different experimental examples, not only solids dissolved in liquids, but also liquids in liquids, as well as substances dissolved in water, substances dissolved in organic solvents and substances that were not dissolved at all. The experiments were contrasted to each other, and together with the teachers' dialogue with the students, this had an immediate effect on the test results. At the end of the first lesson, the teacher stated: "We can conclude that two liquids can form a solution also; it is not always solid substances that are dissolved," a statement he also wrote on the whiteboard.

"Explain, as well as you can, what a solution is" showed once again to be the most informative question on the test. Even if a few more students tried to answer the question at a molecular level, they were still quite few, and only two students in this first cycle of the study answered in a way that showed some insight into the particulate character of the solvents. The majority of the students still answered the question at a macroscopic level using everyday language. Six students did not answer the question at all, or in an irrelevant way. According to our experience, those particular students are most often unwilling to answer open questions, as they have difficulties in expressing themselves when writing.

Revising the lesson

The revision of the lesson plan went quickly, thanks to the sharp focus on the critical aspects of the object of learning. The result of the post-test led to the conclusion that the macroscopic view still dominated and that the sub-microscopic level was not explained clearly enough during the lesson. In the discussions at the third meeting, we realized that we had to focus on the molecular level already at the beginning of the lesson:

> Peter: When we have that group of beakers with substances that are not dissolved, we can talk about the micro level, and what has happened with the particles in those cases?
>
> Gunilla: And what has happened in the beakers where it is dissolved, what is the difference at the micro level?
>
> Anna: And we can point out "equal dissolves equal" earlier also.
>
> Kerstin: And that the solvent water consists of particles too, that are also scattered in the solution, just as the molecules in the solutes are.

Monica: We have to emphasize "water molecules," not just "water."

Parviz: They have to understand that there is empty space between the water molecules.

Kerstin: Yes, it might be a good idea to talk earlier about the more abstract theories. Our aim is that they should see the differences and similarities at the micro level and relate them to the groups of concrete examples. Why are they dissolved? What does it mean, what has happened with the particles? And the ones that are not dissolved; what about the particles there?

Result of the second lesson

Teacher 2 carried out the revised lesson and the post-test. The lesson plan was more or less the same, with the difference that the molecular level was pointed out from the start in the dialogue with the students, and over and over again in direct connection with the macroscopic observations of the concrete experimental examples given.

The result in the post-test in this class showed further improvement in students' learning. The number of students that answered question 1 and 2 correctly had increased compared to the first class. But the most interesting result was the one that question 3 exposed; more than one-third of the students in cycle 2 now explained what a solution is at the sub-microscopic level using chemistry terms. A revealing example of one student's answer was: "When salt is dissolved in water, the crystals are divided into small, small particles and they are evenly spread out between the water molecules."

Nevertheless, the majority of the students in this class still explained what a solution is at a macroscopic level, a result in line with the findings presented in Calýk *et al.* (2005): students' lack of sub-microscopic explanations for macroscopic observations along with a preference for the use of everyday language. A common way of explaining a solution within this group could be: "When something is dissolved, it is so small that we can't see it anymore, and nothing is left on the bottom or at the surface of the beaker."

Revising the last lesson and a comparison of the enacted objects of learning

The difficulty in helping students correctly answer questions in the sub-microscopic categories was eagerly discussed among us at the fourth meeting:

Kerstin: I think that they can answer at the micro level, but they don't understand that this is important.

Anna: Maybe we should point out the qualitative differences between different kinds of answers? We can refer to the demands for different grades in the syllabus; a higher remark demands using chemical concepts, such as molecules.

Gunilla: That is chemistry!

Anna: Yes, we have to think of this already in 7th grade; make the demands and the qualitative differences between answers clearer.

Researcher: You are doing experiments at the macro level, but you talk at the micro level; the connection between the two levels has to become clearer.

Even if the lesson plan was not changed in any significant way after the fourth meeting, the discussions played an important role when the third teacher carried out the lesson with her students. Parviz's comment about "empty space" concerned experience gained in learning studies 1 and 2. The notion of empty space between atoms and molecules was assumed to be critical in order to understand the particulate character of matter, "Without empty space in-between, there are no particles," as Peter expressed it. In lesson 2 and 3, both teachers pointed this out very clearly not just by talking about the particles in the solute, but also by emphasizing the empty space between the particles in the solvent. Teacher 3 pointed out the molecular level even more frequently than teacher 2 had done.

Analysis of the video recorded lessons showed the differences in how the object of learning was enacted in the three lessons, and can be illustrated with excerpts from the dialogues between teachers and students. In lesson 1, the teacher did not mention the particles in the solute or the solvent until the end of the lesson, and then quite briefly. Instead, the teacher focussed on the macroscopic level in the dialogue and on what could be visually observed in the experiments. What was soluble and what was not was clearly shown by contrasting different experimental examples and underlined by notes on the whiteboard, but the sub-microscopic level stayed hidden.

Excerpt from lesson 1:

Teacher 1: Now I have mixed sugar and water, is it dissolved or [. . .]?

Student: It is dissolved!

Teacher 1: Yes, as you can see, there is no sugar at the bottom of the beaker; you cannot see it anymore. I put this beaker on the left side on the desk.

[. . .].

Teacher 1: What about oil and water?

Student: The oil stays on the surface.

Teacher: Yes, it is not dissolved. It is not possible to dissolve oil in water; they are too unequal. This beaker shall be placed on the right side.

[. . .].

Teacher 1: If we mix salt and oil then?

Student: The salt sinks to the bottom.

Teacher: Salt cannot be dissolved in oil.

[. . .].

Teacher 1: Now we can try oil and gasoline, what happens?

Student: It dissolves.

Teacher: Yes, it does; they are equal.

This can be compared to the way the teacher in the third lesson discussed the experiments with the students. The contrasting experiments at the macroscopic level, together with the simultaneous dialogue at the sub-microscopic level, then led to general insights:

Excerpt from lesson 3:

Teacher 3: I mix sugar and water […]

Student 1: It stays on the bottom.

Teacher 3: Does it? Come and have a closer look!

(The student gets up.)

Student 1: The sugar is gone.

Teacher 3: Is it gone? What has happened?

Student 2: The same thing as with salt.

Teacher 3: What do you mean when you say "the same thing"?

Student 2: The sugar molecules are in between the water molecules.

[…].

Teacher 3: What about water and oil?

Student: There is a layer on the surface.

Teacher 3: Yes, the oil molecules stay there.

[…].

Teacher 3: If we try water and alcohol? (mixes)

Student: It is dissolved.

Teacher 3: Where are the molecules?

Student: The alcohol molecules are in the empty space between the water molecules.

The teacher in lesson 3 also gave examples of qualitative differences between macroscopic and sub-microscopic ways of describing a solution as well as the difference between everyday language and scientific language. In that way, the teacher created patterns of variation that made it possible for students to discern what it meant to answer at a molecular level:

Teacher 3: In the pre-test, many of you described a solution as when a substance cannot be seen anymore; there is nothing left at the bottom or at the surface of the solution; it is transparent. That is correct, but you can also answer that question in a different way. If you want a higher mark in chemistry, I want you to use chemistry language and answer the question I have asked so many times during this lesson: "Where are the particles?" What is the answer then?

Student 1: In the empty space between the water molecules.

Teacher 3: And if it is oil and petrol?

Student 2: Then it is in the empty space between the oil molecules.

Teacher 3: That is a better answer, at a higher level.

Student 3: And if it is not dissolved, one can say that it has not come into the empty space!

Teacher 3: Precisely!

Summary of the test results

As previously stated, the results of test questions 1 and 2 regarding what was soluble, and what was not, were quite satisfying already after lesson 1, with a small improvement in lesson 2 and 3. Test question 3, on the other hand, is worth more attention.

Table I shows a summary of the results of test question 3.

The critical aspect of Category B is that the answers only concern what can be observed visually, for example: "It is a solution when it is transparent; there is nothing left at the bottom, and no layer at the surface." In Category C, the particles in the solute, such as salt, are noted: "The salt is divided into small, small particles that are evenly distributed in the water." The most complex category, Category D, includes answers where the particles in both the solute and the solvent are involved: "For example, when sugar is dissolved, the sugar molecules are spread out in the empty space between the water molecules."

In regards to the question, "Explain, as well as you can, what a solution is," five students in the pre-test in teacher 3's class did not answer at all (Category A), but in the post-test everyone did. Three-fourths of the students answered on the macroscopic level in the pre-test; half of them in the post-test (Category B). No one answered the question at a molecular level while using scientific concepts in the pre-test, while ten students showed satisfying insight into what a solution is on the post-test and expressed it with chemistry terminology (Category C and D). It is worth noting that both teacher 2's and teacher 3's efforts to point out the particles not only in the solute, but also in the different solvents, had an effect on students' answers (Category D). One student in teacher 3's class answered: "A solution is when the particles that are dissolved are spread out equally in the empty space between the water molecules (or oil molecules)."

The number of students in the pre-test, in the lesson and in the post-test was not the same. Some students in the post-test were not present during the lesson, and the number of days that elapsed between the lesson and the post-test varied with each class. The instructions introducing the tests, time factors and other things varied also. This means that the test situations were not controlled or equal. This may have influenced the results in Table I, which therefore should be considered in this context. Reliable data of individual students' presence at the research lessons were not collected, and as the student tests were answered anonymous it was not possible to include only the students who were present in the lesson, and had taken both the pre- and post-test in the analysis. We regret this, as it might have made the improvements in the post-test more genuine. Nevertheless, it can be concluded that a significant number of students developed the ability to describe what a solution is on a molecular level. Even more, this can be explained as a consequence of the developed quality of the lessons in terms of the possibilities of learning that were offered as it was possible for students to discern the macroscopic and sub-microscopic levels simultaneously in lesson 2 and 3.

What can be learned from a learning study? Summarizing remarks and discussion

The identified critical aspects are the result of a learning study, and in this study, the most critical aspect was the notion of "empty space," which points out the particulate character of matter. Other features that are important for students to discern are the differences and similarities between water – as a solvent that can dissolve small, polar molecules – and organic solvents – that can dissolve large, non-polar ones – further, the differences between solutions that are homogenous and mixtures that are heterogeneous, both at the macroscopic and at the sub-microscopic level. It became obvious that it was necessary to point out that a solution can consist of two liquids, and not just a solid substance dissolved in a liquid. At the final meeting, we agreed that we had to continue with gases dissolved in liquids as well as gases in gases in future lessons. More general aspects brought forth by the study were the differences between everyday language and language used in chemistry, as well as the qualitative difference between an answer at a macroscopic level and an answer at the molecular level.

Is it possible to transfer these findings into other contexts, to other teachers and students? Kullberg (2010) and Runesson and Gustafsson (2010) state that it is not possible to make lists of critical aspects and use them statically in new contexts; they must always be seen as relative to the learners as neither general nor unique. But they also found that critical aspects identified in learning studies can be used as resources in novel situations, and that teachers are able to adjust them to new contexts. Kerstin gave an example when she mentioned that she had used findings from this learning study when teaching electrochemistry: "I showed that even if salt and sugar are similar when it comes to solubility, they are different in this case; only a solution of salt can be an electrolyte." Just as it is not possible to transfer critical aspects as a list, it is not possible to transfer a lesson plan from one context to another. Vikström (2005) showed that even if a group of teachers reach consensus about an object of learning and its critical aspects and use the same lesson plan, there will still be differences in the learning outcomes among the students, not only due to the differences between the students' individual qualifications, but also due to the object of learning that was enacted in the classroom. It is the enacted object of learning that makes the difference; how the object of learning is dealt with in the classroom (Marton and Morris, 2002; Marton and Lo, 2007). The patterns of variation were constructed by varying means in Vikström's (2005) study as well as in the learning study described in this paper, but the linguistic ones in the interaction between teacher and students turned out to be the most important since distinctions made in the dialogue enabled the students to discern the variation and gain generalized knowledge.

Table I.
Results of test question 3 "Explain, as well as you can, what a solution is"

Lesson	Category A Irrelevant or no answer	Category B Macroscopic answer	Category C Sub-microscopic answer concerning the solute	Category D Sub-microscopic answer concerning both the solute and the solvent
1	Pre-test: 7 Post-test: 6	Pre-test: 12 Post-test: 8	Pre-test: 1 Post-test: 5	Pre-test: 1 Post-test: 2
2	Pre-test: 0 Post-test: 1	Pre-test: 14 Post-test: 11	Pre-test: 0 Post-test: 0	Pre-test: 2 Post-test: 8
3	Pre-test: 5 Post-test: 0	Pre-test: 16 Post-test: 10	Pre-test: 0 Post-test: 2	Pre-test: 0 Post-test: 8

When we investigated our students' conceptions of matter and solution chemistry, we made the same findings as educational researchers had made long before us. But more importantly, we could transform that knowledge into concrete teaching actions that improved our students learning. Instead of calling attention to students' misconceptions, we asked ourselves: "What does it mean to understand this, and how can we make the necessary critical aspects distinct and clear to our students?" With variation theory as a guiding principle, we managed to create patterns of variation that made learning possible. Just as in Holmqvist (2011), this learning study shows how we used variation theory when discussing the relationship between teaching and learning, and that the theory made the discussions more detailed and specific.

Carlgren (2010) describes education as a non-progressive sector, a sector in which productivity does not rise. It is known that teachers do not always use existing educational research results and Carlgren therefore argues for re-establishing teacher-led research and development in schools and that teachers in a learning study can become producers of knowledge relevant to classroom practice. Results from traditional science education research can without doubt be useful when teaching science, but it is evident that the implementation of the results is limited among science teachers. If variation is a prerequisite for students' learning, we can assume that this is the case also for teachers' learning and professional development. From this follows that it is not enough to present research results to teachers and expect them to transform them into effective teaching actions in their daily work. In the first learning study, we were skeptical about some science education research results presented to us; we did not find them useful, and it was taken for granted that our students already grasped the particulate character of matter. Teachers' unwillingness to respond to challenges regarding subject matter is also described in Adamson and Walker (2011). But through the pre- and post-tests, and by analyzing the differences in students' learning as well as by watching our colleagues' different ways of handling the same object of learning, we became able to discern the critical aspects, and realize what created the differences. Learning studies might therefore be a tool for implementing and making use of educational research results, and moreover, to produce new and useful knowledge. This learning study might not have been realized without the participation of the researcher, but it was our own solutions to our own problems with chemistry teaching that were found and articulated.

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Further reading

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