J Sci Teacher Educ
DOI 10.1007/s10972-014-9397-9

What Makes the Difference? Teachers Explore What Must be Taught and What Must be Learned in Order to Understand the Particulate Character of Matter

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Abstract The concept of matter, especially its particulate nature, is acknowledged as being one of the key concept areas in learning science. Within the framework of learning studies and variation theory, and with results from science education research as a starting point, six lower secondary school science teachers tried to enhance students' learning by exploring what must be learnt in order to understand the concept in specific way. It was found that variation theory was a useful guiding principle when teachers are engaged in pedagogical design, analysis of lessons, and evaluation of students learning, as well as a valuable tool for adapting research results into practice.

Keywords Variation theory · Learning studies · The concept of matter · Professional development

Introduction

This study reports findings from six science teachers' collaborative work concerning teaching the concept of matter. In collaboration with a researcher (author), the six teachers conducted three learning studies within the framework of variation theory (Chik, Pong, & Lo, 2005; Lo, 2012; Marton & Booth, 1997; Marton & Pang, 2006; Marton & Tsui, 2004). All three learning studies were informed by results from science education research and concerned three different science contents; atoms and molecules, photosynthesis, and solution chemistry. The different contents that were dealt with had one thing in common; to understand the phenomena presupposed an understanding of the particulate character of matter. The teachers'

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Published online: 25 September 2014

ongoing exploration of the concept of matter throughout all three learning studies caught the researcher's interest in regards to how the teachers used variation theory and how they applied research results in their own practice. Therefore, the research questions addressed in this article are:

> How can teachers use variation theory as a guiding principle when trying to overcome students' learning difficulties regarding the concept of matter?
> How can the framework of learning studies be used when teachers adapt research results to their own teaching practice?

The concept of matter, especially its particulate character, has been of great interest for science education researchers for decades (Driver & Easley, 1978). Research in this area has identified a variety of students' conceptions regarding the nature of matter. For example, it is found that students often regard matter as static, continuous, and non-particulate, in contrast to the scientific, atomistic, and dynamic view. Students might view atoms as small pieces of substance obtained by dividing matter into "bits" varying in shape and size, where the particle at the micro level has the same characteristics as the substance at the macro level. It is also shown that students do not always perceive the difference between matter and energy, that they might not recognize that atoms are everywhere—in all kinds of objects—around us, and that they struggle to understand "empty space" between particles. The fact that students often lack sub-microscopic explanations for macroscopic observations of phenomena is also well known, and switching between particle models and observable phenomena can therefore be an overwhelming conceptual demand (Andersson, 1990; Beerenwinkel, Parchman, & Gräsel, 2010; De Jong, Van Driel, & Verloop, 2005; Driver, Guesne, & Tiberghien, 1985; Driver, 1994; Harrison & Treagust, 2002; Krnel, Watson, & Glazar, 1998, 2005; Renström, Andersson, & Marton, 1990). At the secondary level, students are taught to interpret phenomena in chemistry in terms of particle models and explain them using scientific language, known among science teachers as a difficult task.

The Theoretical Framework: Variation Theory as a Guiding Principle in Teaching

Research indicates that teachers' competence and what teachers know and do have a direct impact on the quality of students' learning (Darling-Hammond & Bransford, 2005; Hattie, 2009). Many studies have focused on the effects of teaching styles and strategies, but for example Pong and Morris (2001) argue that these have only a peripheral influence on students' learning and that the goal is to make specific content available to learners.

Results from science education research can be useful for teachers, but the question is how to turn them into practical use in classrooms. How can research results be transferred and adjusted into an effective teaching practice that really improves students' learning? What happens when teachers make use of research results and explore them further in their own practice, guided by a specific pedagogical theory? According to Appelton (2003), theory does not necessarily help teachers formulate activities that work on a daily basis in the classroom. Nuthall (2004) also addressed the "theory–practice gap" and noted that a useful theory should function as a guiding principle and an explanatory model for understanding the relationship between teaching and learning, thus leading teachers to more easily understand what to look for, and how to interpret that relationship.

Variation theory (Lo, 2012; Marton & Booth, 1997; Marton & Pang, 2006; Marton & Tsui, 2004; Runesson, 2006) represents a theoretical framework that can guide teachers in their practice in order to find out what has to be done to provide students with the necessary learning opportunities. Pang and Ling (2012) demonstrate the power of the theory in explaining and predicting the relationship between what takes place in the classroom and what students learn, and how ways of improving student learning through teacher professional development can be identified. Also, Bussey, Orgill, and Crippen (2013) encourage the use of variation theory within the chemical education research community as a mechanism for further examination of students' understanding of chemical concepts, as well as a way to improve practice and Elliot's (2012) evaluation of learning studies in Hong Kong supports the view that teachers' curriculum development was enhanced by the use of variation theory.

In a learning study project in Singapore, aiming to help teachers overcome pedagogical challenges, Tan and Nashon (2013) captured three aspects of the participating teachers' learning: (1) increased degrees of student-centered pedagogy and challenges to teachers' prior assumptions about science pedagogy, (2) increased awareness of possibilities and limitations of their beliefs about science pedagogy, and (3) emergence of new understanding about new curricular content and science pedagogy. Pang and Ling (2012) also suggested that learning studies enhances student learning by promoting teacher professional development.

The object of learning is variation theory's point of departure. It concerns a specific way of understanding something, such as a particular content taught in school (Marton & Booth, 1997).

The primary contribution of the theory is that it narrows the focus on that "something" at which learning is directed. The focus is then not only upon the logic of the subject matter itself, but also upon the logic of the students, that is, the various ways the students experience the object of learning. It can therefore be used as a tool to understand some of the necessary conditions for learning and to help teachers make wise decisions when teaching (Ling & Marton, 2012; Lo, 2012; Marton & Pang, 2006).

To experience an object of learning in a certain way, the learner has to be able to discern certain aspects of that object at the same time (Marton & Booth, 1997; Marton & Tsui, 2004) For example: In variation theory, a student learns a new way to experience the characteristics of matter when he or she is simultaneously aware of the particles' movements and the empty space between them, and no longer view matter as continuous and static.

Any content has many aspects, but not all aspects are critical, in regards to the specific object of learning. Learning is a function of discernment, and discernment is a function of variation. We cannot discern a critical aspect of an object of learning if we do not experience some kind of variation, or contrast, in relation to that aspect (Marton & Tsui, 2004). We can become aware of a critical aspect by experiencing a contrast, as in contrasting matter (with mass) with energy (without mass). That contrast, provided that we experience the two concepts at the same time, may help us realize that sunlight and heat have no mass. Therefore, to make learning possible, certain patterns of variation must be manifested in the classroom, patterns that make simultaneous discernment of critical aspects and features possible (Marton & Tsui, 2004).Traditionally, teachers often give many examples of the same thing in their attempts to show similarities in order to promote a general understanding. What variation theory tells us, however, is how important it is to show differences. If we want to know what something is, we also have to know what it is *not*. The fundamental conjecture of the theory is that new meanings are acquired from experiencing differences against a background of sameness, rather than experiencing sameness against a background of differences (Pang & Marton, 2013).

The object of learning is dynamic in nature. A teacher's intended object of learning may be different from the one that is enacted in the lesson, and whether students learn or not depends on what they actually experience in the classroom as well as their prior knowledge (Lo, 2012). Vikström (2008) 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 how the object of learning was enacted in the classroom. Students' learning difficulties can often be explained by the fact that they never had the opportunity to discern the critical aspects, not because they were less able (Vikström, 2008; Lo, 2012).

Variation theory has much in common with established teaching principles: Teachers have to take into consideration the knowledge and understanding that students bring with them; they must teach subject matter in depth; and metacognitive skills must be integrated (Lo, 2012). The theory also serves as a detailed guide for teachers. By exploring different ways of understanding something, i.e., which critical aspects are discerned (or not) by students, variation theory can help teachers understand the qualitative differences in their students' experience with an object of learning and continuously assess how students' ways of seeing change throughout the learning process. This, in turn, helps the teacher give students the appropriate feedback. The idea of "teaching in depth" can also be clarified and made more explicit as critical aspects and patterns of variation for effective teaching and learning are found (Ling & Marton, 2012; Lo, 2012; Marton & Booth, 1997).

The collaborative work carried out in learning studies can be seen as similar to what Elliot (2012), with reference to Dewey, labels as a "laboratory model" for curriculum development. From a Deweyan perspective, teaching is an experimental science where ideas are tested in classrooms conceived as laboratories. According to this view, the laboratory model aims to give teachers an opportunity to pose intellectual questions about the subject matter they are to teach and have their theoretical understanding inform the development of their practice (Elliot, 2012). It can also be labeled as a research-based strategy for professional development embedded at the school-building level around meaningful topics in a collaborative format that has impact on student learning (Lumpe, 2007).

Methods

The overall study consisted of two parts, each requiring different methods. First, teachers explored their own science teaching and their students' learning in the learning studies. This part concerned methods for the teachers' own learning. Second, the researcher collected data and analyzed how variation theory was used when the teachers applied research results into their teaching practice in their attempts to improve student learning. This part concerned methods for how to best answer the overraching research questions.

Part One—The Learning Studies: Teachers Learn by Exploring Their Own Practice

In general, a learning study involves teachers, often in collaboration with a researcher, in research lessons that are designed, observed, analyzed, and modified in a cyclic way. The approach has been well documented by for example Chik et al. (2005), Holmqvist, Gustavsson, and Wernberg (2008), and Lo (2012). The overall aim for a learning study is to find out why certain objects of learning are difficult to understand as well as to find the best ways to improve teaching and learning those objects. The main research problem is simple: "How can the object of learning "X" be taught so that students can see "X" in the way intended?" (Pang & Ling, 2012).

The cyclic process in a learning study involves the steps shown in Fig. 1:

Three learning studies, consisting of three lessons each, were carried out as described in Fig. 1.

Six teachers participated in the study. They all worked at the same school, volunteered to be part of the project, and were selected because they were able to receive the support from their principal that was required to be part of this time-consuming project. All of them were experienced science teachers, but not familiar with educational research. The school has about 300 students in grades 7–9, and 61 students (aged 13–14) in three different classes participated in the three learning studies: the first and the second one in the students' seventh school year, and the third one in their eighth. Three learning studies were conducted from September 2010 to December 2011.

All six teachers participated in the group meetings where student tests and lessons were planned and analyzed. Five group meetings, lasting about 4 h each, were carried out in each study: Two meetings before the first lesson; one meeting between the first and second lesson; one meeting between the second and the third lesson; and one meeting after the third lesson. Three teachers volunteered to conduct the video-recorded lessons. The order in which the teachers carried out the lessons were changed in each learning study, meaning that the first lesson was taught by teacher A in her class in the first study, by teacher B in his class in the second, and so on. It was the lessons that were compared and analyzed, not the individual teacher or group of students. Three lessons, conducted in different classes, were analyzed within each learning study; nine lessons altogether, each lesson lasting about 45 min. The design of the study is summarized in Fig. 2 below.

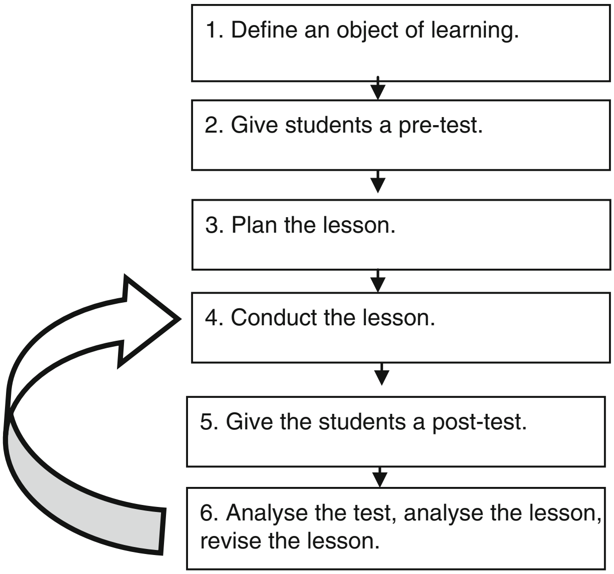

Fig. 1 Basic steps of a learning study

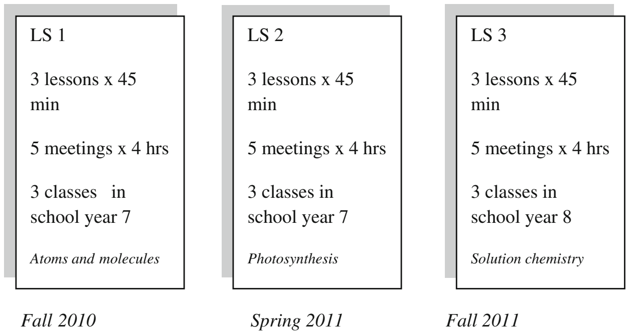

Fig. 2 Design of the study

The lessons, as well as the tests, were approached as a shared responsibility and were planned and analyzed by the six teachers in collaboration. The researcher influenced the process by posing critical questions based on variation theory and research results, but it was the teachers who were responsible for the tests and lesson plans and how to enact them.

Variation theory has its origin in phenomenography (Marton & Booth, 1997), which describes the limited numbers of qualitatively different ways individuals can experience the same phenomenon. Using variation theory when evaluating the pre- and posttests meant they were analyzed on a collective level, revealing qualitatively different ways of understanding the object of learning in the specific group of students. Both the researcher and the teachers analyzed the pre- and posttests independently of each other. At the group meetings, the results of those analyses were compared and found to match.

The video-recorded lessons, observed carefully, made it possible to see what actually happened during the lessons. The recordings were analyzed in collaboration. The researcher and the teachers took turns stopping the film when something interesting showed up that could reveal critical aspects of students' learning and bring to light the relationship between the teaching and the learning of those aspects. Variation theory was used as a guiding principle throughout the whole process:

1. Focus on the object of learning: Trying to identify the critical aspects students must discern in order to understand the object of learning.
2. Applying three kinds of variation in the process:
    a. Variation in students' ways of understanding the object of learning.
    b. Variation in teachers' understanding and ways of dealing with the object of learning.
    c. Variation as a guiding principle for pedagogical design; identifying critical aspects of the object of learning and creating patterns of variation in a systematic way to enable students to discern those aspects of the subject matter (Ling, Chik, & Pang, 2006; Lo, 2012; Pang & Ling, 2012).

Table 1 shows the questions that were formulated when the different elements of the learning studies were analyzed.

Within the learning study framework it became possible for the teachers to learn about the relationship between teaching and learning, in short, what was intended; what was enacted; and what was learned.

Table 1 The collaborative analysis of the learning studies

Element of the learning study	Questions asked	Desired information
Student pretest	What is the students' prior knowledge? What critical aspects are not discerned? How can we categorize the result on a collective level?	Critical aspects that define different ways of understanding the object of learning and critical aspects that need to be pointed out in the lesson
Planning the lesson	How can we use variation in order to point out the critical aspects?	Patterns of variation that can be used and tested when teaching the lesson
Analysis of the lesson in light of the results of the student posttest	What weaknesses remain in students' learning? How were these aspects dealt with during the lesson? What was possible to discern and what was not? How can the lesson be revised accordingly?	Patterns of variation that improved students learning

Table 2 Analysis of how variation theory and research results were used

Data	Questions regarding the concept of matter	Desired information
Group meetings	How were aspects found to be critical? What patterns of variation were created when planning the lessons? How were science education research results applied? How was students' learning evaluated?	Teachers' ability to use theory when planning and analyzing lessons, as well as analyzing the results for students' learning
Video-recorded lessons	What patterns of variation were enacted in the lesson? How were these patterns enacted?	Teachers' ability to translate their findings into teaching activities

Part Two: Data Collection and Analysis of the How Variation Theory was Used When Trying to Enhance Students' Learning of the Concept of Matter

The role of the researcher in this project was to contribute her knowledge about science education research and variation theory and to study how the teachers made use of variation theory in their practice. The teachers were informed about variation theory in the first learning study through lectures and articles. In the third cycle, it had become more of a "lived" theory—a natural part of how lessons were planned and how student tests were constructed and analyzed.

The researcher collected data throughout the whole process. The video-recorded lessons and student tests were supported by the discussions at the group meetings, which were also tape-recorded, transcribed verbatim, and analyzed by the researcher, making it possible to follow the process. The focus of the researcher's analysis was on how the teachers made use of variation theory in all parts of the process that concerned the concept of matter. Table 2 shows the questions that were focused in the researcher's analysis.

Results

The result of this study should be considered on two levels. One level consists of the findings that were made about teaching and learning the concept of matter in this specific group of teachers and students (Table 1). The other level addresses how learning studies, variation theory, and results from science education research were used to make those findings (Table 2). The two levels are intertwined in the description of the result, as the first level illustrates the second. The description of the processes that took place in the learning studies therefore includes the answers to the research questions.

The details and results of each individual learning study will not be described here. Instead, examples of how the teachers used variation theory when dealing with students learning difficulties regarding the concept of matter will be presented.

In the first learning study, the teachers focused more on general teaching actions and less on the object of learning than they did in the third study. Through collaboration with the researcher, the teachers became more familiar with results from science education research as well as with variation theory and it became possible for them to share a common ground with the researcher as well as with each other. The teacher Anna's comment "Our way of talking to each other has changed, now we talk about the same things!" illustrates how she experienced the process in the first learning study, when compared to the third study where the teachers' discussions and ways of offering the students the object of learning became much more specific, a result supported by Holmqvist (2011) who also conducted three learning studies with a group of teachers during three semesters.

The teachers found that certain ways of dealing with the content made a difference in their students' learning. They became able to articulate what their students had to discern in order to understand the concept of matter, especially its particulate character, in a specific way. The teaching actions and strategies that were carried out addressed the fact that some concepts had to be treated simultaneously and contrasted against each other. When summarizing their experiences, the teachers concluded that the critical aspects regarding the concept of matter when teaching science were:

1. The importance of pointing out that atoms build up everything material around us, as well as the importance of making a connection between the macroscopic and sub-microscopic level, by pointing out that all kinds of things (such as air, a saucepan, a flower, or water), can be divided into smaller and smaller parts down to the atomic level.
2. The importance of pointing out where atoms are *not*, (as in sunlight or heat), by treating the concepts of matter and energy simultaneously.
3. The importance of pointing out the empty space between particles (atoms and molecules) when explaining a phenomenon (such as dissolution) at a sub-microscopic level.
4. The importance of making a connection between observable phenomena in experiments at a macroscopic level and the corresponding explanations at the sub-microscopic level by dealing with both levels simultaneously.
5. The importance of pointing out that a phenomenon can be described in qualitatively different ways by comparing how the same phenomenon can be described using everyday language as well as scientific language.

How did the teachers use variation theory in their search for these critical aspects (1–5 above), and how did this improve students learning?

Atoms Build Up Everything Material Around Us

The teachers' traditional way of teaching the content "atoms and molecules", as well as the textbooks that were used, started by presenting Bohr's model of the atom. It was taken for granted that the students understood that atoms exist in everything around us but not in for example sunlight or heat. Moreover, the teachers', as well as the text books', traditional way of presenting the concepts of matter and energy, was to present one thing at a time—the concept of matter in chemistry lessons in grade 7, and the concept of energy in physics lessons in grade 9. Research results (for example Driver, 1994) that were presented to the teachers at the first group meeting in learning study 1 were something the teachers never had thought about. Therefore, this was investigated in the pretest in the first learning study where students were asked to circle examples they considered to be built up of atoms. The result surprised the teachers—95 % of the students were more or less unsure of where atoms are and where they are not.

Thus, the teachers concluded that this was a critical aspect, and a lesson plan with appropriate patterns of variation was agreed upon. Groups of students were asked to divide different well-known objects (air, water, chair, ear, etc.) into smaller and smaller pieces, moving from a macroscopic level to a sub-microscopic level. The groups presented their results and the teacher took notes on the whiteboard. After intensive discussions, a conclusion could be drawn: All the examples were built up of atoms and all of them had mass.

Where are Atoms Not?

Following variation theory, and in order to create a contrast, the second part of the lesson concerned where atoms are *not*. New examples were given (sunlight, lamplight, and heat). The task was the same as with the material examples. The students came up with more or less imaginative suggestions, but soon they realized that it was impossible to divide the new examples into smaller components or particles in the same way.

The posttest after the first lesson in learning study 1 showed some improvements in students' learning, but the result was not satisfying as a majority of the students still could not separate matter from energy. Therefore, the teachers revised the lesson plan so the contrast between the two concepts was expressed more clearly. For example, after lesson 1, the teachers realized that it was not a good idea to ask the students, "What is sunlight *made of?*" as they had done with the material objects, as it could lead the students to think of light as something material. It was better to ask, "Is it possible to do the same thing with sunlight and heat as we did with the previous examples?"

In both lesson 1 and lesson 2, the concept of matter and the concept of energy were dealt with in a sequence, one at a time. After lesson 2, the teachers concluded that the way they took notes on the whiteboard could be used to discuss them simultaneously and thereby create a clearer contrast. Therefore, in lesson 3, the material examples at different organization levels (from the macroscopic to the sub-microscopic level) were written down on the left and the examples of forms of energy on the right. This strategy made it possible to compare the examples at the end of the lesson and to discern and underline the differences between the two. For example, the examples on the left were possible to collect and weigh, while this was

Table 3 Test results from learning study 1: "circle all the examples that are built up of atoms"

	Number of students who circled only the examples built up of atoms in the pretest	Number of students who circled only the examples built up of atoms in the posttest
Students in lesson 1 ($n = 18$)	2 (10 %)	5 (27 %)
Students in lesson 2 ($n = 20$)	1 (5 %)	14 (70 %)
Students in lesson 3 ($n = 18$)	0	16 (88 %)

impossible with the ones on the right. The contrast between matter and energy now became more explicit and furthered the students' understanding.

In the posttest after lesson 3, 88 % the students (compared to 0 in the pretest) in this class managed to circle all the given examples correctly.

This approach to teaching the concepts of matter and energy was new to the teachers; they had never given it any thought before. Guided by variation theory, the teachers realized the importance of comparing the two concepts by dealing with them simultaneously. Before, the concept of matter and the concept of energy had always been taught in different lessons, never treated at the same time, and thus, the contrast between them had never been possible to discern. This is an example of a knowledge gap, where teachers unknowingly ignore aspects that are critical for students' learning. It is difficult for teachers to discern critical aspects if they themselves do not have problems discerning them (Lo, 2012).

In short, it was found that it became possible for the students to discern where atoms are and where they are not by questioning what was earlier taken for granted and by consciously creating patterns of variation. Most importantly, the difference between matter and energy was possible to discern by treating the concepts simultaneously, which was a result of the teachers using variation theory as a guiding principle when revising the lessons (Table 3).

The Empty Space Between Particles and the Connection Between the Macroscopic and Sub-microscopic Level

The importance of pointing out the connection between the macroscopic and the sub-microscopic world was found already in learning study 1 (as described above) when the students were offered insight to the fact that atoms are everywhere around us. This was further investigated in learning study 3 where the value of focusing on the empty space between particles was explored.

The fact that matter consists of moving particles with empty space between them was part of the object of learning already in the first learning study in the fall of 2010. Research results (for example Harrison & Treagust, 2002; Krnel et al., 1998, 2005) of students' difficulties with understanding "empty space" were presented to the teachers and was then met with skepticism, and one teacher said: "It is the particles that are important, not what is between them, we must focus on the particles!" Later on, after learning study 3, the same teacher expressed, "There are no particles if there is no empty space between them," and his colleague admitted, "We did not realize how important this is, but now we do!". One of the test questions in the first learning study in 2010 was: "Explain why 1 dl of water +1 dl of water makes 2 dl, but 1 dl of water +1 dl of salt only makes 1.5 dl?" The idea behind this question was to investigate whether the students could use the concept of the particulate character of matter in their explanations. Learning study 1 showed that a majority of the students, even after being taught, were more or less unable to answer that question at a molecular level; they lacked the necessary understanding, and the particulate character of the solvent (water) was hardly expressed at all.

Learning study 2 and the three lessons about photosynthesis were more or less considered failures. Even if students' understanding of the content improved, the weak results strengthened the teachers' opinion that their students' lack of understanding of the particulate character of matter was a serious obstacle for learning science.

The remaining difficulty in understanding the concept of matter was the reason the teachers chose solution chemistry as the content in learning study 3 in the fall of 2011. During the discussions in the group in learning study 3, it was concluded that certain efforts had to be made to make the sub-microscopic level possible to discern for students. When dealing with solution chemistry the year before, the focus had been on the conditions that influenced the dissolution process, such as stirring, pulverizing, and temperature—something that the teachers now realized did not support the students' comprehension at the molecular level.

The discussions at the group meetings led to insights that the particulate character of water and other solvents, not only the solutes, should be taken into account, and that examples should be given of liquids dissolving in other liquids, not only of solids in liquids, in order to create patterns of variation.

The teachers learned that "empty space" between sub-microscopic particles was a critical feature by being presented with research results by the researcher, as well as by studying their own students' learning, and they now realized that they had to pay attention to the notion of "empty space".

The most informative test question in learning study 3 was: "Explain, in as much detail as you can, what a solution is." A majority, 94 %, described solutions at a macroscopic level, using everyday language in the pretest: "A solution is for example when you dissolve something, like salt, in water, and it becomes transparent, you cannot see it anymore." During the posttest after the first lesson in the cycle, 7 students (out of 21) gave an answer at a molecular level, but only 2 of them touched on the particles in both the solute and the solvent. The teachers realized that it was important that the students understand that both the solute and the solvent consist of particles and that a prerequisite was to understand "empty space." So, one critical question that was raised when revising this first lesson was: "What does it take for our students to discern the critical feature of "empty space"?

During the posttests after lessons 2 and 3, on the other hand, 18 students out of 40 (45 %) managed to express themselves at a molecular level using terms and concepts from chemistry. As many as 16 of them gave complex answers, involving both the particles in the solute and the solvent: "For example, when sugar is dissolved, the sugar molecules in the crystals are spread out in the empty space between the water molecules." It became clear that revising the lesson made a difference in students' learning.

What can explain the differences in students' learning between lesson 1 and lessons 2 and 3? Analysis of the video-recorded lessons showed the differences in how the object of learning was enacted in the lessons and can be illustrated with excerpts from the dialogues between teachers and students. When analyzing lesson 1, the teachers noticed that the particles in the solute were not mentioned until the end of the lesson, and only briefly. The particles in the solvents were not mentioned at all. Instead, the teacher in that first lesson focused on the macroscopic level and on what could be visually observed in the experiments. The macroscopic level, what was soluble and what was not, on the other hand, was clearly shown by contrasting different examples, underlined by placing the beakers on different sides of the desk and by taking notes at the whiteboard. When analyzing the first lesson in learning study 3, the teachers concluded that the macroscopic level of solution chemistry was dealt with quite well, while the sub-microscopic level remained more or less hidden. Below is an excerpt that illustrates the teachers focus on the macroscopic level in that first lesson.

Excerpt from Lesson 1 in Learning Study 3

Teacher C	Now I have mixed sugar and water, is it dissolved or…?
Student 1	It is dissolved!
Teacher C	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 of the desk

…..

Teacher C	What about oil and water?
Student 2	The oil stays on the surface
Teacher C	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 C	If we mix salt and oil then?
Student 3	The salt sinks to the bottom
Teacher	Salt cannot be dissolved in oil

…..

Teacher C	Now we can try oil and gasoline, what happens?
Student 4	It dissolves
Teacher C	Yes, it does; they are equal

The excerpt above shows an example of how the teacher in lesson 1 focused on what could be directly observed in the experiments. Patterns of variation were created that made it possible for the students to separate water-soluble substances from ones soluble in organic solvents. No patterns at all were created that made it possible to discern the particulate character of the solvents. When the teachers analyzed the video-recording from this lesson and discussed the possibilities for learning that were given, they found that the macroscopic view had dominated the lesson and the sub-microscopic level was never clearly explained. They then revised the lesson plan accordingly by focusing on this critical aspect from the beginning of the lesson. Below is an excerpt from the group meeting where the lesson was revised:

Excerpt from Group Meeting 3, Preceding Lesson 2; Lesson Revision

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 "like dissolves like" 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 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?

Discussions like the one above led to changes in the lesson plan before lessons 2 and 3 and it was decided to discuss what happened with the particles at the sub-microscopic level already from the start of the lesson. The excerpt from the dialogue between teacher and students in lesson 1 above can be compared to the dialogue between the teacher and her students in lesson 3, when exactly the same experiments were discussed. The experiments at the macroscopic level, together with the dialogue at the sub-microscopic level, led to general insights:

Excerpt from Lesson 3 in Learning Study 3

Teacher A	I mix sugar and water…
Student 1	It stays on the bottom
Teacher A	Does it? Come and have a closer look!

(The student gets up.)

Student 1	The sugar is gone
Teacher A	Is it gone? What has happened?
Student 2	The same thing as with salt
Teacher A	What do you mean when you say "the same thing"?
Student 2	The sugar molecules are in between the water molecules

…..

Teacher A	What about water and oil?
Student 3	There is a layer on the surface
Teacher	Yes, the oil molecules stay there

…..

Teacher A	If we try water and alcohol? (mixes)
Student 4	It is dissolved
Teacher A	Where are the molecules?
Student 4	The alcohol molecules are in the empty space between the water molecules

This excerpt shows that even a small change in dealing with content can cause a large change in the patterns of variation and in the object of learning that is enacted. This in turn might explain the difference in students' learning between lessons 1 and 3. The dialogue in the interaction between teacher and students turned out to be the most important. The teacher contrasted soluble substances against non-soluble ones in the experiments at the macroscopic level. But at the same time, in her interaction with the students, she focused on the sub-microscopic level; the particles and the empty space between them in each experiment. Distinctions made in the dialogue enabled the students to discern the variation and develop their understanding of the particulate character of matter.

The excerpts from lesson 1 and lesson 3 above illustrate how the teachers dealt with "empty space" in different ways. The teacher in lesson 1 did not enact this feature at all, while the teacher in lesson 3 did so frequently. The excerpts also illustrate how the sub-microscopic level was connected with observations at the macroscopic level in lesson 3, which was not the case in lesson 1.

The Qualitative Difference Between Explanations with Everyday or Scientific Language

The importance of pointing out the difference between everyday and scientific language was also discussed in the group meeting preceding lesson 3 and was seen as a complementary reason for the improvement of the answers to the test question, "Explain, in as much detail as you can, what a solution is" in the last posttest. That students have difficulties with "talking and writing science" was well known to the participating teachers, and the answers given in the open test questions in all three learning studies supported the fact that the students had problems expressing themselves using scientific terms at a sub-microscopic level. The discussions about the use of language and the connections between scientific language and test results were enriched by variation theory as it made the teachers aware of the value of comparing answers of different qualities. Teacher A in lesson 3 gave her students examples of how a phenomenon, like dissolution of salt in water, can be described in different ways; on a macroscopic level using everyday language and on a sub-microscopic level using chemistry terms and concepts. Thus, the teacher created patterns of variation that made it possible for students to discern that the same phenomenon can be described in qualitatively different ways.

Table 4 Test results: "explain, in as much detail as you can, what a solution is"

Test	Number of answers at a macroscopic level in the pre- and posttest	Number of answers at a sub-microscopic level concerning only the solute in the pre- and posttest	Number of answers at a sub-microscopic level concerning both the solute and the solvent in e pre- and posttest
Students in lesson 1 ($n = 21$)(Teacher C)	Pretest: 20 (95 %) Posttest: 14 (67 %)	Pretest: 1 (4 %) Posttest: 5 (24 %)	Pretest: 0 Posttest: 2 (9 %)
Students in lesson 2 ($n = 20$) (Teacher B)	Pretest: 17 (85 %) Posttest: 12 (60 %)	Pretest: 3 (15 %) Posttest: 0	Pretest: 0 Posttest: 8 (40 %)
Students in lesson 3 ($n = 20$) (Teacher A)	Pretest: 20 (100 %) Posttest: 10 (50 %)	Pretest: 0 Posttest: 2 (10 %)	Pretest: 0 Posttest: 8 (40 %)

As shown in Table 4 below, 10 students (out of 20) in the posttest after lesson 3 answered the question, "Explain, in as much detail as you can, what a solution is," on a molecular level while none of them did this in the pretest. As many as 8 of them mentioned the particles in both the solvent and the solute.

Conclusions

Results from many learning studies within a wide range of topics have been published (Lo, 2012). What is generally shown is that learning studies can reveal what is required for students to understand certain things in certain ways. This is also the case here. It was found that certain ways of dealing with the content made a difference in the students' learning. By contrasting matter and energy; by connecting the macroscopic and the sub-microscopic level; and by drawing attention to "empty space," patterns of variation were created that improved students' understanding of the concept of matter. Moreover, making clear the difference between everyday language and scientific language enhanced the students' ability to express themselves in a more complex and scientific way. It was found that variation theory could be used as a guiding principle throughout the process; in lesson design as well as when evaluating students' learning in relation to the learning possibilities that were offered in the classroom. In general, the teachers found that changes in the lesson plans and in the enactment of the lessons—regarding aspects that were possible, or not possible, to discern—were reflected in the students' learning. It could be argued that it is helpful to make certain differences visible to students by treating concepts simultaneously and not one at a time (as often is the case in traditional science text books and teaching) and that discernment of these differences is what improves students' learning. It can also be argued that it is small—often neglected, often linguistic—differences in the enacted object of learning that truly creates change. Something that is not argued here, however, is that creating the conditions for discernment necessarily means that all students will discern the critical aspects and learn more or less automatically; only that it at least becomes possible for students to learn what was intended, an argument supported by Ling et al. (2006). What is unique with this study is that it focuses on teachers' exploration of critical aspects of a specific concept, the concept of matter, that were found in three different learning studies about three different topics. However, in order to prove the validity of the teachers' findings, it is necessary to conduct further research and evaluate whether the critical aspects identified in these particular learning studies can be used as resources in novel situations, across different science topics and domains, and by teachers in different contexts. If so, learning studies might open up opportunities for teachers to make an original contribution to pedagogical knowledge in the field of science education that other teachers might find useful, as Elliot (2013) argues.

Hence, throughout the learning studies and supported by variation theory, a "science of teaching" (Elliot, 2012) was developed as teachers were given an opportunity to pose critical questions about the subject matter they were to teach, as well as about their own tacit and largely unexamined theories about the minds of learners and learning. Before the learning studies, the teachers who participated were well aware of the fact that their students had difficulties understanding the concept of matter as well as the fact that this influenced the students' understanding of almost every scientific phenomenon. However, the teachers were unable to express in detail exactly what those difficulties consisted of. By participating in the learning studies, they became aware of things they had previously taken for granted; they became able to define critical aspects that they had not been aware of before; and they became able to design their lessons based on these findings. With findings from science education research as a point of departure, the teachers used the "laboratory model" (Elliot, 2012) and variation theory in their search for critical aspects and worked out lesson plans that made it possible for their students to discern these critical aspects.

Even if results from science education research from decades ago pointed out the learning difficulties students have with the concept of matter, it is clear that those difficulties persist along with the "theory and practice gap" (Nuthall, 2004). Throughout the project addressed in this article, the teachers used results from science education research as a resource. On the outset, research results were sometimes met with skepticism. For example, it was taken for granted that students knew the fundamental difference between matter and energy, and also that atoms make up everything we can observe around us. However, the learning study framework made it possible for the teachers to study students' understanding in a systematic way and realize that their findings were in line with what researchers already have found. Guided by variation theory, they then integrated research results as well as their own findings into their teaching practice in a way that improved students' learning. Consequently, the teachers reevaluated their opinions about science teaching and educational research, a result similar to the learning study project described by Tan and Nashon (2013).

The overall conclusion (and suggestion) is that learning studies and variation theory are fruitful ways to overcome the "theory and practice gap" that Nuthall (2004) addressed, as well as useful tools for teachers' professional development.

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