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**Extended summary**

What makes the difference?
Teachers' collective exploration of the concept of matter as an object of learning

*The study*
Within science education research it is well known that students' understanding of matter is crucial for their further understanding of a range of science phenomena. An ongoing research project, funded by the Swedish Research Council, investigated how teachers' professional learning develops as a shared practice. In three learning study cycles five teachers, working with students at the age of 13, explored the concept of matter as a prerequisite of understanding the three different objects of learning that were dealt with, and what could be done in practise to support students´ learning.

Students' tests, video-recorded lessons, and discussions, served as instruments for the teachers in their investigations. The researcher used the same data sources, along with teacher interviews, when analysing the character of the findings made by the teachers.

Variation theory served as a tool for the teachers' common knowledge development. The teachers developed their ability to point out critical aspects, identify necessary conditions for students' learning, and enact their produced knowledge in teaching situations.

*The objects of learning*
The teachers chose objects of learning which they had found difficult to teach. The first learning study focused upon matter in general. The objectives were to offer the students the ability to point out where atoms existed and where they did not, to arrange subjects in different organisation levels such as "chair-wood–cellulose-molecule-atom," and to realize that there is empty space between molecules and atoms. Photosynthesis was the subject in the second study, and special attention was paid to the fact that plants are mainly built from invisible carbon dioxide from the air. The goal of understanding "empty space" was not at all accomplished in the first study, so the teachers decided to explore it further in the third cycle where the content was chemical solutions.

*Critical aspect 1: The difference between matter and energy*
It was found that it is crucial to point out what matter is not, i.e. to create a contrast to the concept of energy. The pre-test showed that the students often did not realize that everything around us consists of atoms; for example, they could answer that atoms did not exist in common objects, such as a chair. On the other hand, light and heat might well consist of atoms. When understanding this—through activities in the first learning study that clearly pointed out the contrast—the students improved their test results significantly.

In the second learning study, focused on photosynthesis, this critical aspect was further investigated. In this new context it became even clearer that the difference between matter and energy was critical as students often talked about plants as "made of soil and sunshine". Photosynthesis is known to be a difficult subject, but the learning study helped the teachers to

find out in detail what was difficult, and what could be done about it. Several conclusions were made; for example, the importance of putting nutrients in the background and instead focusing on the carbon atom and the huge amount of carbon dioxide that is needed when a plant grows. In this learning study, as well as in the first one, it also became obvious that the relationship between matter at the macro level (such as trees, air, water) and matter at the micro level (i.e. molecules of oxygen, carbon dioxide and glucose) was important for the students to discern. In this learning study, the students' test results also improved, but not as much as the teachers had hoped. The teachers concluded that the chosen object of learning was too vast and complex.

*Critical aspect 2: The empty space*
Another finding, throughout the three studies, was the importance of pointing out the empty space between molecules, something that was made possible for the students to discern by contrasting the view of matter as static and homogenous at the macro level with the view of matter as dynamic and non-homogenous at the micro level.

At first, the teachers were not convinced that the aspect of "empty space" was critical, but as the three learning studies progressed, the teachers explored the aspect in ways that changed their own understanding of it, as well as their way of enacting it in the classroom, something that clearly supported students' learning. In the first study, the students were faced with the question: "How come 1 dl water + 1 dl water becomes 2 dl of water, while 1 dl of water and 1 dl of salt only becomes 1,5 dl?" Despite the teachers' efforts, the students were in general not able to answer this question in a way that showed insight into what happened at the micro level. The fact that liquids, as well as solids, consist of particles with empty space in between them was found critical.

In the third cycle, understanding solubility was chosen as the object of learning. Here, the critical aspects were well known and accepted, and things that had been taken for granted in the past now were exposed. By creating effective patterns of variation, the teachers were able to improve students' learning drastically. Experiments demonstrated contrasting solubility at the macro level in a conscious way. This way, students could experience the general rule of solubility. But most importantly, the teachers explored the micro level through dialogue with the students: *"When this has dissolved and this has not, what has then happened with the particles?"* The concept of saturation and its relationship to empty space was first explored among the teachers themselves, and later on used as a tool to further the students' understanding. The third cycle is not yet completed, but preliminary results show that the students' ability to answer the above question is improving.