Evaluation of a teaching-learning sequence on the particulate nature of matter using crystal structures

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Abstract. The evaluation of a teaching-learning sequence (TLS) on the particulate nature of matter (PNM) based on crystal structures is presented. The TLS has been developed in a design-based research project. To test if the TLS fosters students' use of the PNM it was introduced to several 8th-grade classes in Vienna. Students' use of the PNM was measured with a pretest and posttest. Preliminary results based on limited data suggest that students use the PNM in the posttest significantly more often. However, regarding phase transitions, most students remain in a continuous perception of matter even after the intervention.

Introduction

People generally get through life without ever having to think about the particulate nature of matter (PNM). Therefore many students think of matter as being continuous [1]. Even more problematic, when students know about atoms and molecules, they tend to transfer the properties of macroscopic objects to submicroscopic particles [2]. For example, they imagine that the size of atoms or molecules changes during a phase transition. Chi *et al.* [3] argue that students' reasoning in that case is based on a *sequential ontology*, although these scientific phenomena (e.g. diffusion, phase transitions) can only be explained with an *emergent ontology*. Consequently, students need to be taught the emergent ontology for them to understand the connections between the macroscopic and submicroscopic levels of matter.

In light of these learning difficulties, the question of how students' understanding of the connections between the macroscopic and submicroscopic levels of matter can be improved was investigated in a doctoral research project. The present study focused on whether a teaching-learning sequence (TLS) based on domain-specific design principles can foster students' use of the PNM.

Methods

The research process is situated within the methodological framework of design-based research [4], which combines evidence-based development of teaching-learning materials with their empirical evaluation. Various approaches to the PNM such as experiments, typographic representations, crystal structures, or 3D models have been examined in 60 interviews with students from two Viennese secondary schools using the method of probing acceptance [5]. The findings of these interviews led to the formulation of domain-specific design principles which informed the design of a TLS on the PNM. For example, crystal structures are used instead of experiments for the introduction of the PNM or typographic representations of particles are used instead of spherical representations.

The TLS was implemented in the classroom by four teachers with 8th-grade students. The effects of the TLS on students' understanding of the relationships between the macroscopic and submicroscopic levels of matter were assessed using questionnaires in pre-post format. Items that were already used in the interviews were supplemented with some items from a German translation of the Chemistry Concept Inventory (CCI) [6] to compile the questionnaire. The pretest contained seven general items on the PNM. The posttest contained those seven identical items plus four more items that were specific to the TLS. Open-ended questions in both tests were analyzed using evaluative qualitative content analysis [7], before making use of descriptive statistics as well as significance testing (t-test, Wilcoxon signed-rank test).

Findings

Based on only preliminary data[1] from 92 students there was a significant difference in average points per student between the pretest ($M = 5.14$, $SD = 2.51$) and posttest ($M = 7.67$, $SD = 2.82$); $t(91) = -7.94$, $p < 0.001$. The effect size ($d = -0.83$) can be interpreted as a high effect of the intervention (the TLS) on students' use of the PNM. This effect was especially relevant regarding students applying the idea of empty space between the particles ($r_B = -0.92$) as well as students connecting temperature with the movement of particles ($r_B = -0.80$).

However, there were also some aspects where students remained in a continuous perception of matter. When having to explain melting and boiling point, hardly any students made use of the PNM. Furthermore, a large number of students still transferred the properties of macroscopic objects to submicroscopic particles when describing solid objects. In reverse, most of the students used the PNM when having to explain the behavior of gaseous objects. This suggests a possible connection between phases of matter and students' conceptions.

Conclusion

The study aimed to evaluate if a TLS based on domain-specific design principles can foster students' use of the PNM. First results based on preliminary data suggest that the TLS overall promotes students using the PNM. However, this can be only said about some aspects (empty space, temperature) of the PNM as students still use a continuous model of matter when explaining phase transitions. If these results remain with the complete data set future research should focus on further improving the TLS and finding a way to foster students' use of the PNM when explaining phase transitions.

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[1] Only two thirds of the data have been collected at the time of abstract submission. Results based on the complete data set will be presented at the conference.