Sequencing Physical Representations With Human Tutors and Virtual Representations With a Computer Tutor in Chemistry

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Abstract: STEM instruction uses physical and virtual representations, which have complementary effects on learning. We present an observational study in which novice students worked collaboratively on chemical bonding. Students were assigned to different orders of physical or virtual representations. A combination of quantitative and qualitative analyses suggests that students engaged in more productive problem-solving strategies if they started with physical representations. They maintained these strategies when switching to virtual representations, which afforded more efficient problem solving.

Introduction

In educational contexts, we face a *representation dilemma* (Dreher & Kuntze, 2014): we ask students to use visual representations that they have never seen before to make sense of content that they have never heard of. Therefore, students need *representational competencies*: knowledge and skills about how to interpret visual representations and how to use them to use them to solve problems (Ainsworth, 2006). Different representation modes have complementary effects on students' learning (de Jong, Linn, & Zacharia, 2013). Physical representations allow for tangible interactions (Figure 1, top). Virtual representations are visual representations that students manipulate via mouse or text input (Figure 1, bottom). When combining these representation modes, the order in which they are provided may matter: there is evidence that students show higher learning gains if they work with physical followed by virtual representations (Smith & Puntambekar, 2010), but there is also evidence that students show higher learning gains if they work with virtual followed by physical representations (Jaakkola & Nurmi, 2008). Based on these contradictory results, it has been proposed that it is not the order that matters, but the affordances the order has for the target concept (Olympiou & Zacharia, 2012).

Yet, we do not yet have a good understanding of how the choice of representation mode and order affects novice students' learning of novel concepts with novel representations. In realistic educational contexts, this question is of practical relevance when teachers have to decide whether to provide computer-based activities with virtual representations or human-led activities with physical representations.

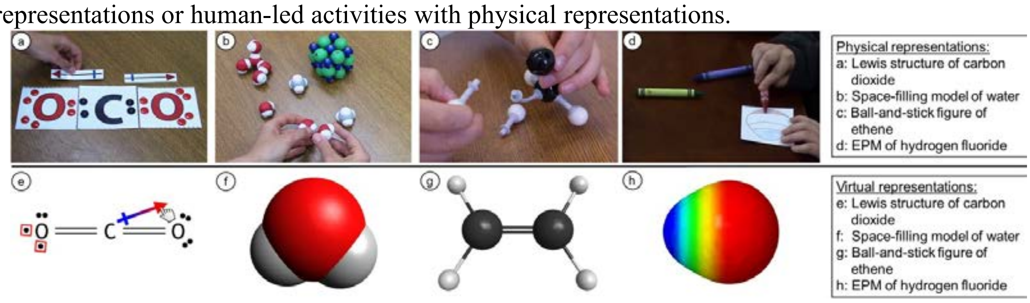

Figure 1. Physical representations (top) and virtual representations (bottom) of chemical molecules.

Methods

We conducted an observational study with twelve students as part of a high-school chemistry workshop. The workshop involved three 3h-long sessions, spread over four weeks. Students had never worked with the visual representations and had no prior knowledge about the target concepts. Students worked collaboratively in dyads that were randomly assigned to physical-then-virtual or virtual-then-physical orders.

During the workshop, students worked on problem-solving tasks introducing them to chemical bonding. When working with *physical representations*, students received a worksheet with several that asking them to construct a physical representation of a molecule, to answer questions about target concepts and about how the representation depicts these concepts. A human tutor provided feedback and assistance the problems. *Virtual representations* were integrated in a computer tutor: Chem Tutor (Rau, 2015), which provided hints and error feedback. Students manipulated the virtual representations to solve problems about chemical bonding. Chem Tutor asked students to explain target concepts and about how the representations depict these concepts.

Students took pre- and posttests. Dyad discourse was transcribed and coded for strategies of problem-solving and reasoning about representations and concepts. Inter-rater reliability was high with kappa = .77.

Results

First, we investigated whether physical and virtual representations have different affordances for problem-solving reasoning strategies. We compared the frequency of codes describing these strategies. We found that when working physical representations, students more often negotiated their answers and planned representations, and engaged in less guessing. Furthermore, students made more connections to representations and concepts. When working with virtual representations, students solved problems more efficiently.

Second, we investigated whether the order of physical and virtual representations has different affordances. We compared the frequency of codes between representation mode orders. The comparison showed that codes that occurred more frequently for physical-then-virtual than for virtual-then-physical orders also occurred more frequently when students worked with physical representations. Thus, it seems that students maintained strategies afforded by their first representation mode when switching to a new representation mode.

Third, we investigated how problem-solving and reasoning strategies related to students' learning success. We compared the frequency of codes between successful dyads with pre-posttest learning gains to unsuccessful dyads without learning gains. We found that codes that occurred frequently in successful dyads occurred more frequently with physical than with virtual representations. They also occurred more frequently with physical-then-virtual than in virtual-then-physical orders. By contrast, codes that occurred more frequently in unsuccessful dyads also occurred more frequently with virtual than with physical representations.

Finally, we used qualitative analyses to gain further insights into how problem-solving and reasoning might relate to learning success. We examined one successful and one unsuccessful dyad. The successful dyad negotiated their answers more often when working with physical representations. These strategies appeared to yield deeper reasoning about representations and concepts. The dyad maintained these strategies when working with virtual representations. By contrast, the unsuccessful dyad often tried to guess answers while working with virtual representations. These strategies seemed to result in more superficial reasoning. They maintained these strategies while working with physical representations and provided incoherent reasoning when making connections to concepts and representations.

Discussion

We investigated affordances of representation mode and order from the perspective of the *representation dilemma* by focusing on students who learned about new concepts with new visual representations. Our findings suggest that physical representations embedded in human tutoring afford problem-solving conducive to reasoning about how visual representations depict abstract concepts. Students seemed to maintain these strategies when switching to virtual representations embedded in a computer tutor, which seemed to afford more efficient problem solving. Because our study is limited due to its small and observational nature, we cannot make causal claims about the effectiveness of representation modes or order. Yet, our findings yield a new testable hypothesis: that novice students may be most successful if a human tutor uses physical representations to introduce novel concepts and then transition to virtual representations embedded in a computer tutor.

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