Taking a New Perspective on Spatial Representations in STEM

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Abstract: Representational competence is a vital capacity in STEM disciplines and students must form strong representational expertise. When translating between highly spatial representations, students can successfully rely on external resources to simplify the process; however, this may come at the expense of producing durable mental representations. Here we introduce a software interface to help chemistry students perform spatially demanding diagram translations. We implicate *embodied perspectives* for addressing the production of such mental representations.

Introduction

Scientists rely on the ability to make fluid translations between external representations within their domain (Kozma, Chin, Russell, & Marx, 2000; Kozma & Russell, 1997). Representational translations are particularly important in the domain of chemistry where students must learn to coordinate molecular diagrams, spectra, formulae, and concrete models to each other as well as to the phenomena they represent. In this discipline, the vast scale that separates the observable world from the represented world uniquely complicates translating among representations and presents a barrier to successful problem solving and conceptual change. As such, improving the ability to move fluently between representations, or *representational competence* (Kozma & Russell), is a central target for instruction and the design of new learning environments in chemistry.

Developing representational competence becomes increasingly important as students progress through the chemistry curriculum. In particular, college level instruction in chemistry emphasizes a highly spatial subset skill of representational competence: performing *representation translation* between standard molecular diagrams. Representation translation between molecular diagrams (hereafter RT) like the Fischer, Dash-Wedge, and Newman projections (see Figure 1) is a difficult task, as students must identify and transform a molecule's 3D spatial relationships through both holistic and internal degrees of freedom. Recently, empirical work has shown that RT can be supported through the use of concrete molecular models (Padalkar & Hegarty, 2012; Stull, Hegarty, Dixon, & Stieff, 2012). However, the utility of concrete models is tempered by reports that students find these models confusing and are unable to use them to solve RT tasks without significant guidance (Stull et al., 2012).

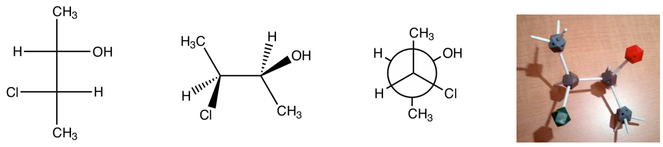

Figure 1. Equivalent representations of (2S,3S)-2-chloro-3-butanol: Fisher projection, Dash-Wedge projection, Newman projection, and concrete model (from left to right).

Stull, Barrett, and Hegarty (2012) have reported that externalizing RT tasks onto virtual molecular models provides students the same benefits found in studies of concrete models for offloading spatial relationships from working memory. Interestingly, Stull and colleagues have also found that students using virtual molecular models were more efficient in answering diagram translation questions and required little to no prior knowledge of chemistry. There is evidence, though, that when students are assessed in absence of such tools, performance on RT suffers (Stieff, Lira, Scopelitis, in preparation). This raises important questions about how students might most productively interact with highly spatial domain content and instructional scaffolds to produce durable mental representations for STEM.

We propose that such durable mental representations may be produced by enlisting the body to perceive structure through *embodied perspectives.* An embodied perspective is the physical alignment of the body in a perspective taking (PT) position relative to a spatial diagram and/or scaffolding representation (e.g., virtual molecular model). Evidence supporting this notion comes from multiple research traditions. Factor analytic work in spatial cognition has found that spatial visualization (mental rotation) and spatial orientation (perspective taking) are correlated but distinct cognitive processes (Hegarty & Waller, 2004). Thus, learning environments enabling PT should still support students with strong mental rotation abilities, but would provide students with weak aptitude for object-based transformations an alternative when working with highly spatial content.

PT construed solely as a mental operation, though, is cognitively expensive and may induce strategy switching (Kozhevnikov & Hegarty, 2001). However, if PT is repositioned as an embodied process, the act of using the body to physically perceive molecular structure becomes a demonstrable process in teaching and learning settings (Scopelitis & Stieff, under review) and may also lead students to produce body-based schema (Wilson, 2002) that encode correspondence between perspective, structure, and structural diagrams. Such schema may then be recalled "off-line" (Wilson, p. 633) to catalyze thinking on similar and novel spatial tasks.

A Software Solution and Further Implications

From known affordances of virtual molecular models and the proposed benefits of embodied perspectives, we introduce a software application that employs head tracking to allow students to embody multiple perspectives on chemical structures. A computer's integrated webcam captures a student's position relative to the screen and transforms it into reciprocated rotations. The virtual molecular model is then exchanged with its diagrammatic equivalent when a student's position aligns with the view encoded in standard structural diagrams (see Figure 2). Additionally, students have immediate access to molecular structure through pre-selected examples and a search field that queries structure data from the National Institutes of Health (NIH) database. Students can enable standard molecular representations (depicted in Figure 1) after centering the molecule along "eligible bonds."

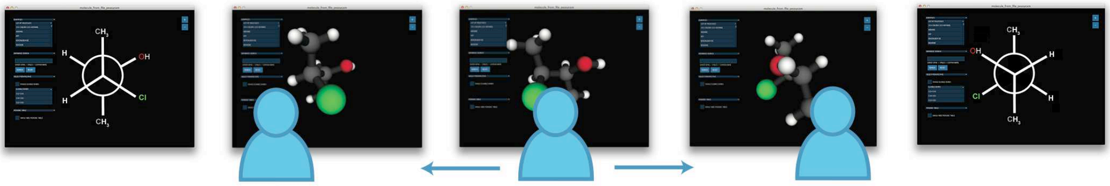

Figure 2. Example of an embodied perspective with the molecule centered along an eligible bond. Students see how a ball and stick representation is exchanged for the appropriate diagram at relevant viewing angles.

We assert that the implications of this software reach beyond the chemistry classroom. The affordance of software learning environments to fluidly exchange representations may be beneficial in building students' understanding of space-diagram correspondence. More significantly, embodied perspectives may serve as a general, instructable process for highly spatial content in any STEM discipline, producing stable mental representations for productive inferential reasoning and problem solving.

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Acknowledgments

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