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Communication

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ConfChem Conference on Interactive Visualizations for Chemistry Teaching and Learning: Research into Practice—Visualizing the Molecular World for a Deep Understanding of Chemistry

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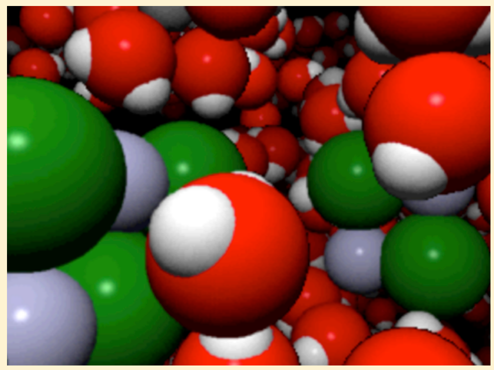
Ⓢ *Supporting Information*

ABSTRACT: A deep understanding of chemistry requires internal visualization of structures and processes at the molecular level to rationalize observable chemical and physical properties, and make sense of chemistry symbolism and mathematical relationships. The paper argues that accurate mental models of the molecular world are needed to address the student misconceptions described in the literature, and describes the potential and limitations of the VisChem animations to develop useful mental models. A constructivist learning design has been developed and evaluated as a best-practice strategy for effectively using the VisChem resources for learning. This communication summarizes one of the invited papers to the Interactive Visualizations for Chemistry Teaching and Learning ACS CHED Committee on Computers in Chemical Education online ConfChem held from May 8 to June 4, 2015. The lively discussions that followed addressed the difficulty of showing the crucial role of ion hydration without producing cognitive overload, the need to build a visual literacy through repeated and progressive use of molecular animations, and the complementary nature of animations and simulations to portray the molecular world.



KEYWORDS: *First-Year Undergraduate/General, Multimedia-Based Learning, Misconceptions/Discrepant Events, Aqueous Solution Chemistry, Constructivism, Molecular Modeling*

The chemistry education literature provides abundant evidence that student misconceptions about the nature of ionic solutions and reactions stem from inadequate mental models of these structures and processes at the molecular level. In this paper[1] and its online discussion (see the Supporting Information), we address the challenges, limitations, and potential of VisChem molecular animations[2] to develop useful mental models, and describe an evidence-informed, constructivist learning design to most effectively present the animations.

The challenge of learning chemistry is to rationalize observable phenomena (like the appearance of a white precipitate) in terms of imperceptible molecular level events (such as ion dehydration and aggregation) and describe these in meaningful symbolic language (chemical formulas and equations). Johnstone's seminal work[3,4] first drew attention to the cognitive demand of seamlessly moving between these three thinking levels. His information processing model explained how this cognitive overload in the working memory led to alternative conceptions and misconceptions due to rushed and inappropriate linking of new ideas (e.g., the formula for sodium carbonate solution is written as "$Na_2CO_3(aq)$") to established ideas in the long term memory (e.g., the formula describes chemical speciation, so there must be a "Na_2CO_3" species in solution—see Figure 3 in the paper[1]). Subsequent studies[5] provided convincing research evidence that students developed misconceptions about the molecular level that were extraordinarily resistant to change, without necessarily affecting student ability to solve traditional algorithmic problems. Unless "sensible" misconceptions are revealed or confronted by disagreement with observable evidence, they will persist, and often interfere with subsequent learning (e.g., if the "Na_2CO_3" species exists in solution, why is the van't Hoff factor for sodium carbonate solution closer to three than one?). Many misconceptions about chemical speciation and processes at the molecular level derive from misinterpretation of chemical formulas and equations, presented before developing a visual model of what they represent.

■ THE VISCHEM PROJECT

A suite of molecular animations was produced in the mid-1990s with care to balance the often competing demands of scientific accuracy, artistic license for clear communication, and technical computing constraints. Each animation was designed to address specific misconceptions,[6] and careful attention was paid to the crucial role of ion hydration, and the competition between often-conflicting processes in chemical reactions. For example, the animation portraying the dissolution of solid sodium

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chloride (watch the animation in Figure 9 in the online supplemental paper[1]) addresses the misconception that the water molecules simply knock out the ions, or "pull" them off easily. In the animation, the removal is portrayed as a struggle between competing forces, reflecting the fact that the process is actually endothermic and the result of the competition between ion-dipole forces and lattice forces is driven only by an increase in the overall entropy of the system. This lays the visual modeling groundwork for a subsequent abstract analysis of the thermodynamic factors involved in such a reaction, illustrating the important point that enthalpy and entropy factors may often have opposing contributions to a spontaneous event.

Interviews with students after watching such animations revealed the occasional misconception was generated too, by mistakenly seeing agency in molecular behavior.[6] One example was the unintended impression that hydrating water molecules appeared to carry AgCl ion pairs toward a growing crystal of AgCl (watch the *VisChem* animation in Figure 7 in the online paper[1]).

Further studies[7] with students revealed that while they liked these representations of phenomena they could not imagine, they were unable to perceive the key visual features in the structures and processes portrayed without assistance. Consequently, they were unable to transfer key ideas to other similar phenomena.

We found that students needed to confront their prior understandings before seeing the animations, and explicitly change any misconceptions after having key features of the animations pointed out. Only then were they able to transfer new insights to new situations. An evidence-based cognitive model[6,7] was used to inform a constructivist learning design to address these steps. The central steps in this design required students to storyboard their mental models before and after having the key features of the animation drawn to their attention. Evidence from student interviews[7] and unpublished eye-tracking studies indicates the combination of the specific steps in the *VisChem* learning design, and attention-focusing strategies (action replay, pre-emptive narration, and highlighting) when presenting animations, is much more effective than just showing the animations without support and guidance. This important pedagogical recommendation will be supported with evidence from present studies in our laboratory.

CONFCHEM: EMERGENT DISCUSSION THEMES

This paper was discussed May 23–27, during the Spring 2015 ConfChem online conference Interactive Visualizations for Chemistry Teaching and Learning hosted by the ACS DivCHED Committee on Computers in Chemical Education.[1]

Participants asked questions about the need to show all the solvent water molecules in the animations portraying an ionic solid dissolving, an ionic solid precipitating, proton transfer between water molecules and acids and bases, and electron transfer between a reducing agent and an oxidizing agent. The point was made that, without sufficient prior exposure to "building-block" animations portraying the reactants (hydrated ions in solution, dissolved molecules, a metal), cognitive overload was inevitable once reactants were mixed and new processes happening.

Suggestions for addition of charge signs on ions, the use of color, and even the possible use of sound to embellish the visual message were discussed. We carefully avoided the risk of reinforcing the misconception that a property of the substance, like metallic luster, was due to a property of its constituent shiny metallic-looking atoms.

Finally, the complementary nature of animations (*choreographed* representations) and simulations (*calculated, probabilistic* representations) was discussed as the best way to portray the molecular world.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00824.

> A paper, modified and adapted for university-level chemistry educators from articles[8,9] written for secondary chemistry teachers in the U.K. and Australia, together with associated discussions from the ConfChem conference, and a link to the *VisChem* Web site with free resources and a demonstration of the learning design (PDF)

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Notes

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REFERENCES

(1) American Chemical Society Division of Chemical Education Committee on Computers in Chemical Education. 2015 Spring ConfChem: Interactive Visualizations for Chemistry Teaching and Learning. http://confchem.ccce.divched.org/2015SpringConfChem (accessed Dec 2015).

(2) Tasker, R. VisChem Project. http://www.vischem.com.au (accessed Dec 2015).

(3) Johnstone, A. H. Macro and microchemistry. *School Sci. Rev.* **1982**, *64*, 377–379.

(4) Johnstone, A. H. Chemical education research in Glasgow in perspective. *Chem. Educ. Res. Pract.* **2006**, *7* (2), 49. http://doi.org/10.1039/b5rp90021b.

(5) Nakhleh, M. B. Are Our Students Conceptual Thinkers or Algorithmic Problem Solvers? *J. Chem. Educ.* **1993**, *70*, 52–55 and references therein..

(6) Tasker, R. Using Multimedia to Visualize the Molecular World: Educational Theory into Practice. In *Chemist's Guide to Effective Teaching*; Pienta, N., Cooper, M., Greenbowe, T., Eds.; Pearson Prentice Hall: Upper Saddle River, NJ, 2005; pp 195–211.

(7) Tasker, R.; Dalton, R. Research into Practice: Visualization of the molecular world using animations. *Chem. Educ. Res. Pract.* **2006**, *7*, 141–159.

(8) Tasker, R. Representing Molecular Behaviour. *Education in Chemistry* **2015**, *52* (May), 20–23.

(9) Tasker, R. Research into Practice: Visualising the Molecular World for a Deep Understanding of Chemistry. *Teaching Science* **2014**, *60* (2), 16–27.

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