The influence of molecular diagrams on chemistry learning

Davenport, J. L., Klahr, D. & Koedinger K.

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Abstract
Do diagrams during instruction always improve learning? Well-controlled studies in cognitive psychology labs have shown that adding a picture to text increases performance on transfer tests (e.g., Mayer, 1999), and researchers have suggested that coordinating multiple representations can lead to deep conceptual understanding (e.g., Ainsworth, 2006). In the current study, we investigated whether diagrams would lead to improved learning when they are incorporated into a required homework assignment in a college chemistry course. Eighty-nine students were randomly assigned to read either a tutorial with molecular level diagrams (Diagram+Text condition) or a tutorial with identical text but no diagrams (Text-only condition). While students in both conditions made significant learning gains from pre to posttest on multiple choice questions ($p < .001$), their performance in Diagrams+Text condition was no different from their performance in the text alone condition on any of our measures: a multiple choice posttest, a problem solving activity, or transfer questions. These results suggest the large effects of diagrams commonly found in laboratory studies may be difficult to replicate in educational settings. Active and intentional coordination of representations may be required if diagrams are to increase learning.

Introduction
When do diagrams improve instruction? Mayer's Multimedia principle proposes that instruction that includes both text and pictures causes students to make connections between representations and leads to more robust learning than instruction with text alone. This multimedia advantage has been shown in domains such as lightning formation, disc brakes and bicycle pumps (see Mayer, 1999 for a review).

Ainsworth's DeFT (Design, Functions, Tasks) framework suggests that one role of multiple representations (such as diagrams and text) is to allow learners to construct a deep understanding of a domain if factors such as prior knowledge, task, and compatibility of representations are taken into account (Ainsworth, 2006). Though the framework offers a number of suggestions for designing instruction with multiple representations, it does not specify what types of representations and tasks are appropriate for different domains.

In the current study we ask whether the presence of diagrams can enhance learning for students studying first year college chemistry. Buffer systems are notoriously difficult to master, so there is great potential for an instructional benefit from enhancement with diagrams. Prior research in chemistry education has shown that molecular level diagrams may improve student learning. However, these studies were conducted over the course of weeks and the content of instruction in the two conditions was not well controlled (see Kozma & Russell, 2005 for a review). Thus, the current study asks whether molecular level diagrams lead to improved learning when the text content is identical between conditions.

Students were randomly assigned to read either the Diagram+Text or Text only version of the tutorial, and learning was assessed through performance on multiple choice questions, quantitative problem solving using a tutor and transfer questions.

Method

Participants. Eighty-nine undergraduate students enrolled in first year chemistry at Carnegie Mellon University participated in this study to fulfill a course requirement.

Materials. All materials were accessed online and consisted of a tutorial on chemical buffer systems, multiple choice pre and posttests, open-ended transfer questions and an interactive problem-solving activity.

Two versions of a tutorial on chemical buffer systems were created. The Diagram+Text tutorial contained molecular level diagrams (see Figure 1.) while the Text-only tutorial had identical text but no diagrams.

Fifteen multiple-choice questions and 4 transfer questions assessed conceptual understanding of buffers. Incorrect answers to the multiple-choice questions included common misconceptions and the same questions were presented at pre and posttest. The open-ended transfer questions required students to integrate the components of the buffer systems and make predictions based on their knowledge.

Finally, students solved quantitative problems using an interactive tutor. Students could receive multiple hints, with a final, bottom-out hint that revealed the correct answer.

Procedure. Students were randomly assigned to either the Diagram+Text (n = 52) or Text only (n= 37) condition. Participants completed the multiple-choice pretest, read through the buffer tutorial and then completed the posttest items (a problem-solving activity, the same 15 multiple choice items and 4 transfer problems).

Results

A mixed 2x2 ANOVA was carried out with format (Diagram+Text vs. Text-only) as a between-subjects variable, time of test (Pre vs. Posttest) as a within-subjects variable and multiple-choice accuracy as the dependent variable. Pretest to posttest gains were significant, $F(1, 87) = 94.4$, $p < .001$, but there was no effect of format, and no interaction between test-time and format. See Table 1.

Each of the 4 transfer questions was scored on a 3 point scale. An ANOVA revealed no significant main effect of tutorial format. See Table 2.

Problem-solving performance was assessed in two ways; percent correct on first try and an assistance score. Percent correct on first try was calculated as the average number of problem steps the student answered correctly with no hints. The assistance score was calculated as the average number of combined hint requests plus incorrect responses per problem step. No significant main effects of format were found for either the percent correct on first try $F(1, 87) = 1.36$, $p = .24$ or for the assistance scores, $F(1,87) = .62$, $p = .43$. See Table 3.

Discussion

Both Diagram+Text and Text-only versions of a tutorial on chemical buffer systems improved student performance on conceptual multiple choice questions from pre to posttest. However, the presence of molecular level diagrams did not enhance student learning as measured by multiple-choice accuracy, problem-solving behavior or transfer question performance.

Why did diagrams fail to improve learning? Ainsworth (2006) speculates that multiple representations will only improve deep conceptual understanding when the representations are translated between each other. The current results suggest that the mere presence of diagrams during instruction does not necessarily prompt active coordination between representations. Because this study was conducted as an assignment in a college chemistry course, no eye movement data was collected and students may have ignored the pictures entirely.

Students may need additional assistance in relating the diagrams to text in order for pictures to enhance learning. Labels may be one way of encouraging this coordination. While the diagrams in our tutorial did not have explicit text labels, Mayer's 1989 studies on understanding disc brakes suggest that illustrations were only effective when accompanied by such labels. Labels without illustrations or illustrations without labels did not provide the same learning advantage.

The current study suggests that strong results in the laboratory may not easily translate into realistic educational settings. Future research will investigate whether prompts to coordinate between text and diagrams will lead to robust learning in the domain of chemistry.

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction, 16(3),* 183-198.

Mayer. R.E. (1999). Multimedia aids to problem-solving transfer. *International Journal of Educational Research, 31,* 611-623.

Mayer, R. E. (1989). Systematic thinking fostered by illustrations in scientific text. *Journal of Educational Psychology, 81,* 240-246.

Kozma, R. & Russell, J. (2005). Multimedia Learning of Chemistry. In R. E. Mayer (Ed.) *The Cambridge Handbook of Multimedia Learning* (pp. 409-428). Cambridge University Press.

Figure 1.
Solid NaOH consists of Na^+ and OH^- ions packed into a crystalline lattice. When this solid is added to water, the ions float apart leading to extra OH^- ions in the water: $NaOH \rightarrow OH^- + Na^+$. As the concentration of OH^- ions goes up, the concentration of H^+ ions goes down. The resulting large concentration of OH^- makes the solution more basic and leads to a dramatic increase in the pH.

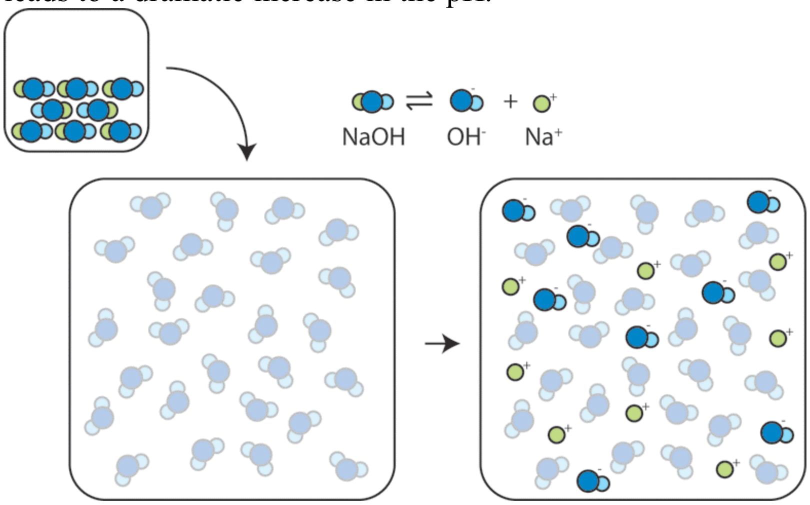

Table 1. Multiple choice test scores by format (Diagram+Text vs. Text-only)

	Diagram+Text (n=52)		Text-only (n=37)	
	M	SD	M	SD
Pre test	.56	.19	.59	.17
Posttest	.75	.18	.75	.17

Table 2. Average transfer question score by format (scored on a 3 point scale)

	Diagram+Text (n=44)		Text only (n=27)	
	M	SD	M	SD
Transfer Qs	1.85	.62	1.96	.60

Table 3. Problem solving results

	Diagram+Text (n=52)		Text only (n=37)	
	M	SD	M	SD
% correct first try	.63	.16	.67	.10
Assistance score	1.05	.75	.95	.65