Drawing for Learning from Dynamic Visualizations in Science

Mike Stieff, University of Illinois-Chicago, mstieff@uic.edu
Katharina Scheiter, Leibniz-Institut für Wissensmedien, k.scheiter@iwm-tuebingen.de
Shaaron Ainsworth, University of Nottingham, Shaaron.Ainsworth@nottingham.ac.uk
Claudia Bohrmann-Linde, University of Tübingen, Claudia.Bohrmann-Linde@uni-tuebingen.de
Max Schall, University of Tübingen, max-fabian.schall@student.uni-tuebingen.de

Abstract: This paper examines the efficacy of drawing for supporting learning from digital media, such as dynamic visualizations. Extant research on the efficacy of drawing for promoting learning from dynamic visualizations is contradictory. The discrepancy in these findings has been attributed to the differences between drawing and dynamic visualizations. While dynamic visualizations emphasize spatiotemporal transformations, drawing emphasizes static spatiotemporal structures. Thus, drawing may impede learning from a dynamic visualization when the target learning objective relates to dynamism as it may bias the learner to focus on structure at the expense of transformation. Here, we present our developing findings that drawing provides an effective learning scaffold for learning from dynamic visualizations more so than self-explanation prompts, and that drawing biases learners to attend to fewer spatiotemporal structures.

Introduction

There has been an increased emphasis on supporting science learning with drawing activities, despite relatively little evidence that drawing is generally an effective learning scaffold when deployed in the science classroom. While several studies (for a review see Van Meter & Firetto, 2013) have shown that drawing can effectively support learning from text, it is not clear that drawing produces the same benefits with other instructional materials. Although it has been argued that drawing is likely to improve learning from dynamic visualizations (e.g., Ainsworth et al., 2011), the empirical evidence demonstrating a reliable effect of drawing remains outstanding. Some early studies have reported evidence that drawing improves learning from animations (Mason, Lowe, & Tornatora, 2013; Zhang & Linn, 2011) and simulations (Stieff, 2011); however, Plötzner and Fillisch (2017) recently demonstrated no significant benefit of drawing for learning from a complex animation.

In contrast to prior claims, these authors argue that dynamic visualizations emphasize complex *spatiotemporal transformations* (i.e., changes among spatial relationships), but drawing emphasizes the construction of a static representation that highlights *spatiotemporal structures* (i.e., geometric entities). Because of the different emphasis of drawing and dynamic visualizations, they suggest that drawing may only improve learning from dynamic visualizations of simple physical systems that focus on spatiotemporal structures. Although the results of this study suggest that drawing biases learners to attend to static features, that work did not include a complex, interactive visualization, nor did the researchers contrast drawing with an alternative scaffold. Here, we compare the efficacy of drawing with and without a dynamic visualization with a highly interactive visualization that enriches the verbal learning material and a study design that included an active comparison group to investigate whether drawing selectively biases learners to focus on transformations.

Present study

The present study examines whether learning from dynamic visualizations is improved by constructing drawings while reading a science text with a complementary visualization. Half of the sample population interacted with a dynamic visualization about chemical equilibrium from *The Connected Chemistry Curriculum* (Stieff et al., 2012) while reading. To identify the interactive benefit of drawing and visualization, these groups were further divided into two groups that either made self-explanation summaries or self-explanation drawings.

Our comparison of interest is the interaction between the two factors: does drawing improve learning from a visualization as much as it improves learning from a science text but not as much as summarizing? Based on prior research from learning with texts that demonstrate a positive effect of drawing, we predicted that drawing would improve learning from the dynamic visualization as much as it improved learning from the text only. Because the visualizations used in this study were highly interactive (i.e., students were directed to manipulate system variables and observe system results), we also predicted that students who construct drawings while learning (with text alone or visualizations) would construct more conceptually accurate drawings that depicted spatiotemporal transformations relevant to the chemical system under study.

Participants

127 students from a mid-sized research-extensive university in Germany participated on a voluntary basis for payment (12€). Students were recruited from a range of liberal arts majors including science and non-science fields. Data from 7 participants were excluded because they did not finish the procedure within the allotted time.

Materials

All participants received an instructional text on chemical equilibrium with five main ideas: the concept of dynamic chemical equilibrium, LeChatelier's Principle, the effect of pressure, temperature, and concentration on the equilibrium position of a reaction. The text was taken from a popular US secondary chemistry textbook (Holt, 2002) and translated into German by a native speaker. The 1875-word text was presented with no accompanying figures and had a Flesch-Kinkaid readability score of 44 on the German readability scale.

In addition to the text, one half of the participants were provided with an interactive simulation from *The Connected Chemistry Curriculum* (Stieff et al., 2012). The simulation presented a reversible chemical reaction at equilibrium. Participants could interact with the simulation to alter the system temperature, pressure, and reactant concentration. The simulation would respond to any manipulation of these parameters with a probabilistic model that restored the system to dynamic equilibrium and a new equilibrium position. The display included not only a dynamic visualization of particle interactions, but dynamic plots of concentration over time.

Embedded within the instructional text were five self-explanation tasks that asked students to explain in their own words the main idea of each section of the text related to the five main ideas. One half of the participants received directions to provide a self-explanation in the format of a written summary and the other half received directions to instead make a sketch for their self-explanation. Participants who received the supporting simulation were instructed to interact with the simulation immediately before generating each self-explanation (drawing or summary) to help them better understand the main idea of the text; participants without the visualization were encouraged to reflect on what they read to respond to the question.

Measures

Chemistry prior knowledge

To control for individual differences in chemistry knowledge, prior knowledge of chemistry was measured with a subset of 10 relevant items of the Chemistry Concepts Inventory, which has been found to be a valid and reliable measure of general chemistry knowledge acquired in secondary education (Barbera, 2013).

Learning outcomes

Learning outcomes were assessed with a summative achievement assessment from *The Connected Chemistry Curriculum*. The 14-item instrument assessed participants' declarative knowledge related to chemical equilibrium, models of dynamic chemical systems, and ability to predict how chemical systems would respond to external stressors (Cronbach's alpha = .85).

Procedure

Participants were tested in groups of up to six, and were randomly assigned to one of four conditions (i.e., text-summary, text-sketch, text+visualization-summary, text+visualization-sketch). Each participant worked individually at a private desk with provided paper, a pen, and a computer, if necessary.

Participants first completed a demographic questionnaire before completing the Paper Folding Test (3 min.), the reading comprehension test (4 min.), and the chemistry prior knowledge test (10 min.). Following the three tests, participants were allotted 45 minutes to complete the learning phase in which they read the text, completed the self-explanation tasks, and interacted with the visualization, if required. Participants were allowed to work through the material at their own pace and were stopped at 45 minutes.

Results

Performance on all measures was determined by calculating and norming the number of correct responses on each measure. The average time to complete the learning phase was 40 minutes and the average number of tasks completed was 4.7. We observed no statistical difference in completion time or the number of completed tasks between groups. After completing the learning phase, the learning outcomes measure was administered with a 20-minute time limit. No differences in reading comprehension or spatial ability between groups was observed.

We qualitatively analyzed the five self-explanation tasks with three binary codes: (1) accurately represents the relevant main idea, (2) references spatiotemporal structures (e.g., particle composition), 3) represents spatiotemporal transformations (e.g., dynamic system changes). Figure 1 illustrates the application of the coding scheme with drawings from two participants. The sketch on the left demonstrates a particle-level representation where the learner has used geometric shapes to demonstrate (inaccurately) changes in particle identity but does not represent how the system changes with increased pressure. The sketch on the right demonstrates a particle-level representation and accurately illustrates how the depicted system would respond to increased pressure with two images that depict the entire system before and after pressure is applied.

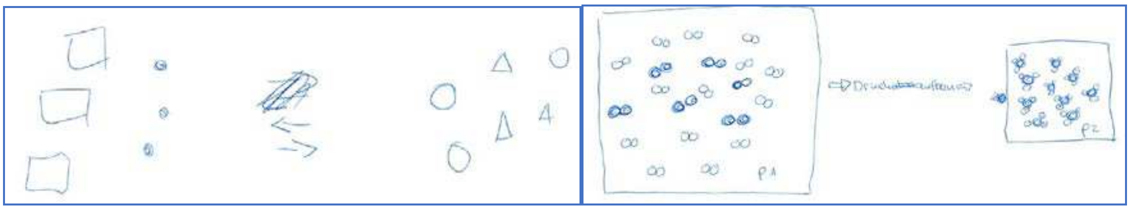

Figure 1. Two sketches from participants illustrating the effect of pressure on dynamic chemical equilibrium.

Does drawing improve learning from dynamic visualizations relative to summarizing?

Post-test achievement was compared with a 2 (text v. text+visualization) x 2 (summary v. sketch) ANCOVA while controlling for prior knowledge. Prior knowledge significantly correlated with learning outcome, $F(1,120) = 5.26$, $p = .02$, $\eta_p^2 = .05$. Although a difference was trending, we observed no main-effect of media, $F(1,120) = 3.13$, $p = .07$. As seen in Figure 2, average student performance was higher in the two conditions with sketching scaffolds than those with summarizing scaffolds. No significant interaction was present in the model, $F < 1$.

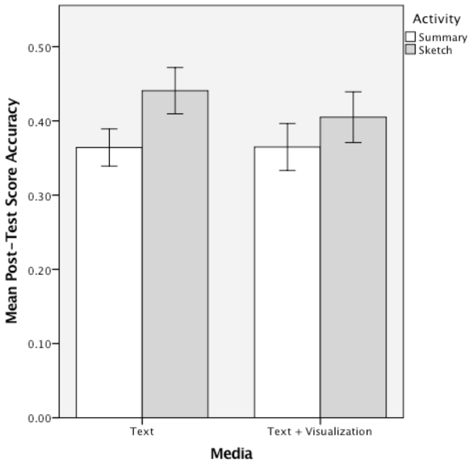

Figure 2. Mean accuracy on post-test assessment of the learning material.

How do learners' self-explanations differ between scaffolds embedded in the learning material?

We analyzed qualitative differences in the participants' self-explanations using three independent 2 (text v. text+visualization) x 2 (summary v. sketch) ANCOVAs, controlling for prior knowledge. First, we analyzed the self-explanations for an accurate depiction of each main idea. We observed no significant differences between scaffold types or learning media and no interaction (all Fs < 1). Second, we analyzed the self-explanations for references to spatiotemporal transformations, such as changes to the system state. We observed that references to transformation information differed significantly between conditions. We observed a main-effect of scaffold ($F(1,120) = 6.04$, $p = .015$, $\eta_p^2 = .05$) but no main-effect of learning media or interaction ($F < 1$). As seen in Figure 3, average occurrences of transformation information were higher with summarizing scaffolds than with sketching scaffolds for both types of media. Third, we analyzed the self-explanations for representations of spatiotemporal structures, such as particle composition. We found that references to structural information differed by scaffold, $F(1,120) = 50.0$, $p < .001$, $\eta_p^2 = .30$ and by learning media ($F(1,120) = 7.51$, $p = .007$) and a trending interaction, ($F(1,120) = 3.56$, $p = .06$). As seen in Figure 3, the average occurrence of structural information was greater with summarizing scaffolds than with sketching scaffolds and greater in text only conditions. The trending interaction suggests that participants who had access to a visualization were much more likely to focus on structural information when they made summaries than when they made sketches.

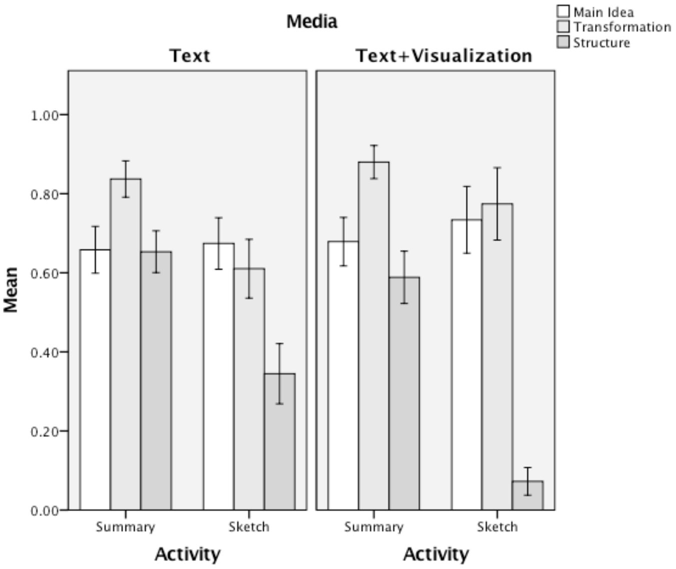

Figure 3. Relative occurrence of each qualitative code in self-explanations during the learning phase.

Discussion and conclusions

While evidence is increasing that dynamic visualizations benefit learning, it is unclear whether this benefit is moderated by the act of drawing. Here, we tested the prediction of Plötzner and Fillisch (2017) by analyzing the content of student-generated representations. We aimed to identify whether drawing supports learning from a visualization and whether drawing biases learners to focus on static features of a visualization. We found that sketching better supports learning from a visualization relative to summarizing. In contrast to prior work, we observed learners represent concepts equally well verbally and pictorially, yet emphasize structural information when learning without a visualization. Understanding whether and how drawing supports learning remains an important target of educational research to support the incorporation of drawing into curriculum reforms. Here, our preliminary analysis suggests that drawing can yield improvements in learning about systems-level processes in science contexts and may improve learning from complex visualizations of those processes.

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Acknowledgments

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