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An adaptive collaboration script for learning with multiple visual representations in chemistry

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A B S T R A C T

Undergraduate STEM instruction increasingly uses educational technologies to support problem-solving activities. Educational technologies offer two key features that may make them particularly effective. First, most problem-solving activities involve multiple visual representations, and many students have difficulties in understanding, constructing, and connecting these representations. Educational technologies can provide adaptive support that helps students make sense of visual representations. Second, many problems with visual representations involve collaboration. However, students often do not collaborate effectively. Educational technologies can provide collaboration scripts that adaptively react to student actions to prompt them to engage in specific effective collaborative behaviors. These observations lead to the hypothesis we tested: that an adaptive collaboration script enhances students' learning of content knowledge from visual representations. We conducted a quasi-experiment with 61 undergraduate students in an introductory chemistry course. A control condition worked on a traditional worksheet that asked students to collaboratively make sense of connections among multiple visual representations. An experimental condition worked on the same problems embedded in an educational technology that provided an adaptive collaboration script. The experimental condition showed significantly higher learning gains on a transfer test immediately after the intervention and on complex concepts on a midterm exam three weeks later.

1. Introduction

Educational technologies offer two features that may make them particularly effective in supporting science, technology, engineering, and math (STEM) instruction. First, they can support students in generating, interpreting, and connecting visual representations. Students often use visual representations to solve problems (Gilbert, 2004; Kozma & Russell, 2005). For example, chemistry students may use ball-and-stick models (Fig. 1A) and draw wedge-dash structures (Fig. 1B) to determine whether molecules are stereoisomers.[1] Educational technologies can automatically grade student-generated representations,

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[1] Stereoisomers are chemical compounds made of the same atoms that differ only in the spatial arrangement of their atoms. Stereoisomers play an important role in chemistry because differences in the atoms' spatial arrangements within molecules can have dramatic effects on the properties of chemical compounds.

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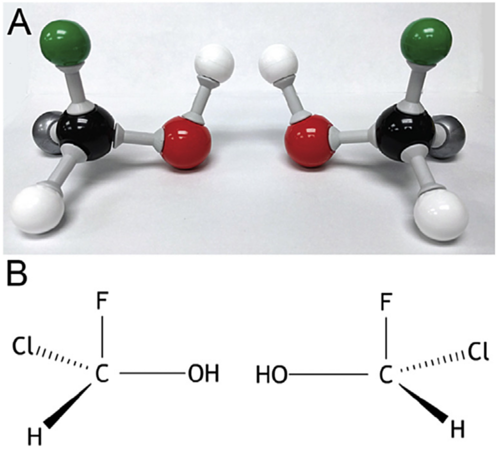

Fig. 1. Physical ball-and-stick model (A) and wedge-dash structure (B) of chlorofluoromethanol. The two molecules in this example are stereoisomers because they have the same molecular formula but the three-dimensional arrangement of the atoms is different; in this case, they are non-superimposable mirror images of one another.

provide real-time feedback on students' interpretations of the representations, and prompt students to make connections between the representations. Such support has been shown to enhance students' learning of content knowledge (Kozma & Russell, 2005; Seufert, 2003).

A second advantage of educational technologies is that they can help students collaborate. Students often use visual representations to solve problems collaboratively (Freeman et al., 2014). For example, students may collaboratively discuss how to combine information from the ball-and-stick models and wedge-dash structures in Fig. 1 to reason about stereoisomers. Educational technologies can support students in collaborating effectively, for example by scripting collaborative activities (e.g., Fischer, Kollar, Stegmann, & Wecker, 2013).

However, prior research has not yet established that collaboration support enhances students' learning of content knowledge from visual representations. This gap leaves the following question open: Does an educational technology that supports students in collaboratively making sense of visual representations enhance their learning of content knowledge?

We addressed this question with a quasi-experiment in an undergraduate chemistry course. We compared two conditions. The control condition worked with a traditional version of a problem that required students to collaboratively discuss connections among visual representations. Specifically, they collaboratively constructed ball-and-stick models and drew wedge-dash drawings (see Fig. 1) on a paper-based worksheet. They did not receive a collaboration script. The experimental condition worked with a technology-enhanced version of the same problems. Specifically, they collaboratively constructed ball-and-stick models and drew wedge-dash structures using an educational technology. The technology incorporated an adaptive collaboration script that prompted students to collaboratively discuss mistakes in their drawings. We tested effects on students' reproduction and transfer of knowledge about the targeted chemistry concepts immediately and three weeks after the experiment.

2. Review of prior research

Most STEM instruction uses visual representations to illustrate important concepts (Ainsworth, 2006; Gilbert, 2008). Because any individual visual representation shows only a particular aspect of the concepts, instruction typically uses *multiple* visual representations that depict complementary information (Ainsworth, 2006; Gilbert, 2008). To integrate this information into a coherent mental model, students need to make connections among visual representations (Ainsworth, 2006; Uttal, 2003). Chemistry is one of many STEM domains in which connection making is critical to students' learning of content knowledge (Talanquer, 2013). The example of stereoisomerism illustrates this point. Stereoisomerism is a complex concept that requires students to understand how differences in atoms' spatial arrangements in otherwise identical molecules affect properties of chemical compounds. The representations in Fig. 1 emphasize complementary information about stereoisomerism: while ball-and-stick models (Fig. 1A) provide tangible information about how the atoms are spatially arranged, wedge-dash structures (Fig. 1B) highlight the identities of the atoms and use more abstract notation to indicate the geometry of molecules. Hence, connection making allows students to combine information about geometry and atom identity to make predictions about reactive behaviors (e.g., acidic character) and macroscopic properties (e.g., melting points) of the substances consisting of the molecules. Furthermore, because wedge-dash structures are the common shorthand chemists use to depict three-dimensional aspects of molecules, it is important that students learn to extract information about the spatial arrangement of atoms in molecules from wedge-dash structures.