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Empirical study

Spontaneous spatial strategy use in learning from scientific text

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ABSTRACT

Two studies explored the role of the spontaneous use of spatial note-taking strategies (i.e., creating maps and drawings) and spatial ability in learning from a scientific passage. In Study 1, college students read and took notes by hand on a 10-paragraph scientific passage about the human respiratory system. Students tended to use verbal strategies such as lists (on 48% of the paragraphs), outlines (29%) and running text (15%), but also used spatial strategies such as maps (28%) and drawings (11%). Regression analyses indicated that spatial ability and the use of spatial strategies (maps or drawings) significantly predicted learning outcomes, with spatial strategy use explaining additional variance beyond spatial ability. In Study 2, students read the same scientific passage and took notes either by hand on paper (paper group), by hand on a large whiteboard (whiteboard group), or on a laptop computer (computer group). A similar general pattern as Study 1 was found for the paper group, but this pattern was not found for the computer or whiteboard groups, suggesting that the relationships found in Study 1 might depend on the note-taking medium. Results also indicated that students in the paper and whiteboard groups spontaneously used more spatial strategies, whereas the computer group tended to use verbal strategies (i.e., words only), suggesting that different note-taking contexts encourage different strategies.

1. Objective

Although much attention has been directed toward the role of spatial ability in learning in science, technology, mathematics and engineering (STEM) disciplines, the present study examines the additional role that might be played by spatial learning strategies – specifically, the spontaneous use of spatial note-taking strategies while studying scientific text. The goals of the present studies are to determine (a) the unique roles of the spontaneous use of spatial note-taking strategies (i.e., creating maps and drawings) and spatial ability in explaining learning from a scientific passage, and (b) whether the medium in with which students take notes (i.e., on paper, on a whiteboard, or on a computer) affects the note-taking strategies that students spontaneously use and the relationship between spatial note-taking strategies and learning outcomes.

2. Rationale

There is now substantial evidence that individual differences in spatial ability predict students' pursuit, persistence, and achievement in STEM disciplines (Wai, Lubinski, & Benbow, 2009). In a massive longitudinal study involving over 400,000 participants, Wai et al. (2009) found that people who scored highly on measures of spatial ability as adolescents were much more likely to achieve advanced degrees and occupations in STEM fields than people with lower spatial ability. Subsequent research has found similar evidence linking spatial ability to STEM learning, likely because many STEM concepts involve representing and manipulating complex spatial relations (Uttal & Cohen, 2012), such as spatial configurations of molecules in chemistry or the structures and processes of the human respiratory system in biology.

One implication of this relationship is to attempt to improve students' general spatial skills through training. If certain spatial skills are important for STEM fields, then targeted training might enhance underlying cognitive processes that ultimately lead to better academic learning. A meta-analysis by Uttal and colleagues (Uttal et al., 2013) found evidence that spatial skills can be improved through training (average Hedge's $g = 0.47$) and can transfer across different measures of spatial ability; however, whether spatial training transfers to authentic STEM learning

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remains unclear. As the authors noted, "...the lack of studies that directly assess the effects of spatial training on performance in a STEM discipline is disappointing" (p. 356). Furthermore, a long history of research on the transfer of learning suggests that transfer is often highly domain-specific (e.g., Mayer & Wittrock, 2006; Salomon & Perkins, 1989; Thorndike & Woodworth, 1901). As one example related to spatial cognition, a study by Sims and Mayer (2002) found that playing the game Tetris improved mental rotation ability only for Tetris-like shapes. In short, the extent to which spatial training yields educationally relevant benefits might be limited, and, at this point, such benefits have not been convincingly demonstrated (Stieff & Uttal, 2015).

This suggests an alternative approach might be appropriate for understanding the relationship between spatial ability and STEM learning, and ultimately, for developing methods to enhance STEM instruction. One possibility is that general spatial ability is related to the use of domain-specific learning and problem-solving strategies. For example, Stieff, Dixon, Ryu, Kumi, and Hegarty (2014) found that training college students on mental imagery and analytic problem-solving strategies in chemistry eliminated gender differences in achievement. This finding suggests that focusing on effective strategy use in a STEM discipline can improve academic performance, and further, that "achievement is dependent not only on spatial ability but also on strategy choice..." (p. 390).

More broadly, a vast research literature demonstrates that learning outcomes largely depend on the quality of strategies students use during learning (Fiorella & Mayer, 2015, 2016; Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013; Weinstein & Mayer, 1985). Popular but suboptimal strategies include rereading, restudying, underlining, highlighting, and verbatim note taking (e.g., Bretzing & Kulhavy, 1979; Callender & McDaniel, 2009; Fowler & Barker, 1974), whereas effective strategies involve deeper generative processing, which require learners to actively organize and integrate the material with their existing knowledge (Fiorella & Mayer, 2015, 2016; Wittrock, 1990) – such as by self-testing, self-explaining, explaining to others, creating a knowledge or concept map, or drawing a diagram (e.g., Fiorella & Mayer, 2013; Roediger & Karpicke, 2006; Schwamborn, Mayer, Thillmann, Leopold, & Leutner, 2010). Importantly, students can be taught to use such strategies effectively with relatively little explicit instruction (Fiorella & Mayer, 2015, 2016; Dunlosky et al., 2013; Weinstein & Mayer, 1985). Thus, strategy use might be more malleable and transferrable to STEM contexts than general spatial ability. The present study focuses on students' spontaneous use of a particular class of strategies – called *spatial learning strategies* (Fiorella & Mayer, 2015, 2016; Holley & Dansereau, 1984) – which are especially useful in understanding STEM concepts.

3. Spatial learning strategies

Learning for understanding involves building a coherent mental model based on the material's underlying structure (Gentner & Stevens, 1983; Kintsch, 1998; Mayer, 2014; Wittrock, 1990), such as understanding a cause-and-effect system or a hierarchy (Cook & Mayer, 1988). Spatial learning strategies help students represent these structural features by making spatial relations among the material more explicit (Holley & Dansereau, 1984; Pressley, 1990). This advantage is especially important when learning from scientific texts, for which no external spatial representations of the material are provided to the learner (e.g., Leopold & Leutner, 2012). Two of the most common forms of spatial strategies are creating knowledge or concept maps, and drawing diagrams.

3.1. Mapping

Learning by mapping involves creating an abstract spatial arrangement of the text by connecting key ideas based on their conceptual relationships (Fiorella & Mayer, 2015, 2016; Holley & Dansereau, 1984). In research on mapping, learners create maps by establishing their own conceptual labels for the relationships, or they might be provided with labels (e.g., "part of," "type of," or "leads to"). A classic study by Holley, Dansereau, McDonald, Garland, and Collins (1979) demonstrates the benefits of teaching students to engage in learning by mapping. College students received training in creating knowledge maps for expository texts (mapping group) or they did not receive training (control group). Then students read a new text on geology while either creating a knowledge map or taking notes normally. The mapping group outperformed the control group on recall and recognition tests, with the strongest effects for lower-achieving students. A subsequent study by Roberts and Dansereau (2008) found that mapping was more effective than creating verbal summaries for students with low verbal ability, but less effective for students with high verbal ability. This suggests that using a spatial strategy such as mapping might be more effective than a verbal strategy for students with low ability, although the study did not include a measure of spatial ability.

A related form of mapping is to create or fill in a graphic organizer or matrix to spatially represent one's notes, such as to represent a compare-and-contrast structure (e.g., Kiewra et al., 1991; Robinson & Kiewra, 1995). For example, in a study by Jairam and Kiewra (2010), college students read a text lesson presented on a computer about different types of wildcats. Students were either asked to take linear notes using a window on the screen or to fill in an onscreen matrix that helped students organize different characteristics attributed to each type of wildcat. Results indicated that students who filled in a matrix organizer during learning performed better on subsequent retention and comprehension tests, compared to students who took notes normally. A more recent study by Ponce and Mayer (2014) provides similar support for asking students to complete a matrix organizer when learning about different types of steamboats. Overall, research on learning by mapping suggests that creating knowledge or concept maps, or using matrix or graphic organizers when learning from text is generally more effective than generating verbal summaries or using one's own note-taking techniques, particularly for low-ability students (Fiorella & Mayer, 2015; Nesbit & Adesope, 2006).

3.2. Drawing

Learning by drawing involves creating a concrete illustration that spatially depicts the key ideas in the text (Fiorella & Mayer, 2015, 2016; Leutner & Schmeck, 2014; Van Meter & Garner, 2005). In a classic study by Alesandrini (1981), college students read a lesson about the chemistry of electric batteries. Some students were asked to create drawings to represent each of the fourteen components described in the lesson (drawing group), whereas other students were asked to use a verbal paraphrase strategy (paraphrase group). The drawing group outperformed the paraphrase group on a subsequent test that included factual, comprehension, and transfer questions, providing early evidence for the benefit of drawing over a purely verbal strategy.

In a more recent study, Leopold and Leutner (2012) compared the effects of creating drawings (drawing group), generating verbal summaries (summary group), or using no strategy (control group), while learning from a scientific text about water molecules. Results indicated that the drawing group outperformed the control group