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The influence of self-efficacy and working memory capacity on problem-solving efficiency

Bobby Hoffman [a,*], Gregory Schraw [b]

[a] University of Central Florida, United States
[b] University of Nevada, Las Vegas, United States

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ABSTRACT

We investigated the influence of self-efficacy beliefs and working memory capacity on mathematical problem-solving performance, response time, and efficiency (i.e., the ratio of problems solved correctly to time). Students completed a letter-recoding task (Experiment 1) or an operation span task (Experiment 2), rated their self-efficacy for solving mental multiplication problems, and then solved similar problems of varying complexity. We tested the *motivational efficiency hypothesis,* which predicted that motivational beliefs, such as self-efficacy, increase problem-solving efficiency through focused effort and strategy use. Experiments 1 and 2 reported a significant effect for self-efficacy on problem-solving performance and efficiency, but limited effects for time. A self-efficacy by working memory interaction occurred in Experiment 1, suggesting self-efficacy is beneficial as demands on working memory increase. These findings suggested that self-efficacy increased problem-solving efficiency through strategic performance rather than faster solution times, and were consistent with the motivational efficiency hypothesis.

1. Introduction

Solving problems accurately and quickly continues to be the hallmark of efficient learners. Problem solving has been studied for decades and a great deal is known about general problem solving (Anderson, 1993; Dewey, 1910; Mayer, 1998), as well as task-specific problem solving in a variety of domains such as mathematics (Ashcraft, 1992; Campbell & Hackett, 1986; Kaye, deWinstanley, Chen, & Bonnefil, 1989; Royer, Tronsky, Chan, Jackson, & Marchant, 1999). Both task- and domain knowledge are essential components of problem-solving accuracy, however, a variety of other variables are related to problem-solving accuracy above and beyond domain knowledge, including self-efficacy beliefs (Lopez, Lent, Brown, & Gore, 1997; Pajares & Kranzler, 1995; Pajares & Miller, 1994), working memory capacity (Adams & Hitch, 1997; DeStefano & LeFevre, 2004; Klein & Bisanz, 2000; Seitz & Schumann-Hengsteler, 2000; Swanson, 2004; Swanson & Beebe-Frankenberger, 2004), and problem complexity (Campbell & Xue, 2001; Hitch, 1978; Logie, Gilhooly, & Wynn, 1994; Mabbott & Bisanz, 2003).

Surprisingly, few studies have examined the role of motivational variables and variables such as working memory capacity, or problem complexity on problem-solving efficiency, which we define as the ratio of the number of problems solved correctly to the amount of time needed to solve them (Mory, 1992). Of special importance to the current research, there are no studies we know of that specifically have examined the influence of self-efficacy beliefs on problem-solving efficiency. The need for efficiency is important as some problem solving situations, such as post-secondary instruction, impose rigid time constraints.

The main goal of the present study was to examine whether self-efficacy beliefs enhance problem-solving efficiency of mental multiplication, while controlling for the variables of working memory capacity and problem complexity. This question is important for both theoretical and practical reasons. From a theoretical perspective, it is unknown whether self-efficacy increases problem-solving efficiency, even though self-efficacy is related to math problem-solving accuracy (Lopez et al., 1997; Pajares & Kranzler, 1995; Pajares & Miller, 1994). We tested the *motivational efficiency hypothesis* (Hoffman & Spatariu, 2008), which predicted that motivational beliefs, such as self-efficacy, increase problem-solving efficiency. It is possible that self-efficacy increases, decreases, or has no effect on response time. Although prior research has shown the positive influence of self-efficacy upon problem-solving accuracy, empirical support for problem-solving efficiency outcomes is lacking.

From a practical perspective, the possible positive effect of self-efficacy on problem-solving efficiency has important implications for understanding the optimal use of limited cognitive resources (Mayer & Moreno, 2003; Paas & van Merriënboer, 1993; Van Gerven, Paas, Van Merriënboer, & Schmidt, 2002). Given that many classrooms have constraints on the problem-solving process, and especially limited time (Marks, 2000), outcomes that seek to understand the relationship between motivational variables and efficiency warrant investigation.

* Corresponding author.
E-mail address: bhoffman@mail.ucf.edu (B. Hoffman).

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1.1. Self-efficacy and mathematical problem-solving

Self-efficacy, defined as the belief in one's ability to organize and execute courses of action to meet desired outcomes (Bandura, 1986), is a powerful intervening variable. The belief that one can perform a task successfully, in many cases, is a better predictor of eventual performance than previous attainments (Bandura, 1986; Pajares, 2002, 2003). Specifically, when controlling for performance accuracy, self-efficacy beliefs have been shown to operate independently of underlying skills, and mediate individual difference variables such as background knowledge (Pajares, 2003; Pajares & Miller, 1994), metacognitive awareness (McCombs & Marzano, 1990; Schunk & Ertmer, 2000), and overall ability (Bandura, 1986; Campbell & Hackett, 1986; Pajares & Kranzler; 1995; Pajares & Miller, 1994).

Self-efficacy beliefs play a powerful role concerning choice, persistence, effort, strategy use, and interest in mathematical problem solving (Lopez et al., 1997; Pajares & Kranzler, 1995; Pajares & Miller, 1994). Self-efficacy for math performance has been linked to selection of a college major (Hackett, 1985), and holds implications for mathematics career choice (Hackett & Betz, 1989). In addition, self-efficacy is positively related to mathematics achievement and problem solving over and above mathematics ability (Pajares & Kranzler, 1995; Pajares & Miller, 1994). Path analysis studies emphasize the predictive ability of self-efficacy by demonstrating self-efficacy either accounts for unique variance beyond factors such as gender, prior experience, perceived usefulness of math and self-concept (Pajares & Miller, 1994), or when controlling for background knowledge (Pajares & Kranzler, 1995). Although ability beliefs are a critical component of self-efficacy assessments, domain interest may be more of a reflection upon outcomes than capability (Lopez et al., 1997). Several meta-analyses have shown that effect sizes attributed to the mediating influence of self-efficacy on performance has ranged from .08 to .38 (Multon, Brown, & Lent, 1991; Stajkovic & Luthans, 1998; Valentine, DuBois, & Cooper, 2004).

Self-efficacy persists over time (Pajares & Graham, 1999), although judgments may change as the perception of task difficulty fluctuates. For example, Stajkovic and Luthans (1998) reported the role of self-efficacy diminished as task complexity increased. Campbell and Hackett (1986) found that self-efficacy assessments for easy tasks are higher due to the expectations of greater task success. However, it is not clear from these studies whether task difficulty and self-efficacy are related to problem-solving efficiency.

Self-efficacy is related to the tactics students will use when solving problems. Bandura (1986) described the connection between a learner's ability to control the learning environment and self-regulation. The sense of control, in turn, enhances the belief about their capabilities and potential to control their destiny (Pajares, 2002). The learner who believes s/he is capable of goal attainment uses more productive metacognitive strategies (Butler & Winne, 1995), works harder, expends more effort, and persists longer (Bandura, 1986; Bouffard-Bouchard, 2001; Lodewyk & Winne, 2005; Schunk & Zimmerman, 2006).

The self-efficacy research mentioned implies two main conclusions. First, self-efficacy is a powerful individual difference variable that is strongly related to academic achievement (Pajares, 1996; Zimmerman, Bandura, & Martinez-Pons, 1992). Strong self-efficacy beliefs can minimize other individual difference factors such as anxiety, physiological predisposition, and interest (Lent, Lopez, Brown, & Gore, 1996).

Second, self-efficacy influences performance beyond existing skills and ability. Even when controlling for general intelligence (Pajares & Kranzler, 1995) or prior math experience (Pajares & Miller, 1994), judgments of self-efficacy predicted achievement outcomes. The beliefs individuals possess concerning anticipated success also determine what challenges individuals attempt (Pajares & Kranzler, 1995). In sum, these studies demonstrate a significant influence of self-efficacy on performance outcomes.

1.2. Working memory, problem complexity, and mathematical problem-solving

Mental arithmetic requires the problem solver to encode the presented information, perform a mental calculation, and provide a response (DeStefano & LeFevre, 2004; Logie et al., 1994). Solving of mental arithmetic involves cognitive processes beyond mere fact retrieval (Seitz & Schumann-Hengsteler, 2000), and is assumed to include both the storage and processing of information (Hitch, 1978; Mabbott & Bisanz, 2003; Swanson & Beebe-Frankenberger, 2004).

Previous research indicates that individuals with higher levels of working memory capacity (WMC) perform better on learning tasks because they have more cognitive resources (Daneman & Carpenter, 1980; Mayer, 2001; Mousavi, Low, & Sweller, 1995). WMC also is positively correlated with general fluid intelligence, (g), (Engle, Kane, & Tuholski, 1999) and speed of processing (Bjorklund, 2005). It is likely that WMC affects cognitive efficiency due to the processing and storage requirements necessary to solve mental problems.

The effect of WMC on math problem solving has been documented in many studies (Adams & Hitch, 1997; DeStefano & LeFevre, 2004; Klein & Bisanz, 2000; Seitz & Schumann-Hengsteler, 2000; Swanson, 2004; Swanson & Beebe-Frankenberger, 2004). The current research used an operations span task to measure WMC and a recoding task to measure short-term memory. Span tasks require participants to solve problems while concurrently remembering either the cumulative sums of a series of problems or a list of words or numbers that follow a sequence of problems. These tasks presumably measure both a basic retrieval mechanism as well as central executive processing (Engle, Tuholski, & Laughlin, 1999; Swanson, 2004; Swanson & Beebe-Frankenberger, 2004). In contrast, a letter-recoding task (Benton, Kraft, Glover, & Plake, 1984) provides a measure of basic storage, such as temporary storage of verbal information in Baddeley's (1998) articulatory loop.

The processing efficiency of working memory is contingent upon both problem complexity (number of digits) and task demand (carry and load demands) (DeStefano & LeFevre, 2004). Kaye et al. (1989) used a dual-task paradigm requiring problem solving and concurrent detection of auditory probes. Dual task conditions are designed to divert memory resources from the primary task of remembering problem solutions. Kaye et al. concluded when participants were required to maintain sums in memory, or attend to dual tasks, response time increased. In a related study, Logie et al. (1994) used adding-span techniques, which involve addition of individual problems while concurrently maintaining a cumulative running total, to study mental arithmetic. Volunteer participants were required to solve either “single carry” or “multiple carry” (p. 399) mental arithmetic problems in both single and dual-task conditions. These studies demonstrated that problem-solving ability was related to the activation of working memory resources, including the central executive, which generally is regarded as the active processing component of working memory (DeStefano & LeFevre, 2004). They also supported the conclusion that as task complexity increases, processing become less efficient by imposing greater demands upon working memory that impede performance (Pollock, Chandler, & Sweller, 2002; Sweller & Chandler, 1994).

A critical variable influencing problem-solving performance is problem complexity. Solving basic multiplication problems, such as 3×4, often involves use of an automated calculation algorithm (Logie et al., 1994) that requires few working memory resources. Solving problems of multiple digits involves greater complexity (Hitch, 1978; Logie et al., 1994; Mabbott & Bisanz, 2003), takes longer (Hitch, 1978; Royer et al., 1999; Siegler, 1988), and requires time consuming mental computations (Campbell & Xue, 2001) resulting in far greater demand on limited cognitive resources.

The research on WMC leads to two main conclusions. First, math problem-solving ability is mediated by WMC (DeStefano & LeFevre, 2004; Logie et al., 1994; Passolunghi & Siegel, 2001; Swanson, 2004; Swanson & Beebe-Frankenberger, 2004). WMC influences how material