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Individual differences in math anxiety and math self-concept promote forgetting in a directed forgetting paradigm

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ABSTRACT

Students whose math self-concept is threatened in stressful classroom situations activate self-defense mechanisms to forget those experiences, which jeopardize future learning and knowledge retention. External cues to forget might be critical to activate these self-defense mechanisms. We tested this idea by employing a directed-forgetting paradigm using math-related materials. Participants were presented with math problems to enhance anxiety, followed by a list of math-related words with instructions to either remember or forget those words. All participants were then asked to remember a second math list. We predicted that people most vulnerable to experiencing threat—those with high math anxiety and high math self-concept—would have the internal motivation to most effectively carry out the forgetting instructions. Participants with high math anxiety and high math self-concept had a greater forgetting score than other participants. These findings are consistent with a motivated forgetting account and suggest that educational materials are susceptible to forgetting.

1. Introduction

Individuals are capable of intentionally forgetting information that they have encoded into long-term memory. By intentional forgetting, we are referring to a goal-directed process in which individuals suppress previously learned information. One way researchers have studied intentional forgetting is through a directed-forgetting paradigm (Bjork, Laberge, & Legrand, 1968). This paradigm explicitly asks people to forget information that they previously encoded into memory. Using the standard list method, participants are presented with a list of words to remember (List 1). Afterwards, half the participants are asked to forget the list (the forget condition) while the other half are asked to remember the list (the remember condition). Both sets of participants then study a second list of words (List 2). Participants in both conditions are then finally asked to recall all words, regardless of the previous remember or forget instructions. Decades of research using the directed forgetting paradigm show that recall for the List 1 words is worse when individuals are directed to forget rather than to remember (i.e., the cost of forget instructions). Participants also commonly recall more List 2 words in the forget condition than participants in the remember condition (i.e., the benefit of forget instructions), presumably because interference is reduced due to the forgetting of List 1 words (e.g., Bjork, 1970). Similarly, participants in the forget condition often remember the List 2 words at a comparable level to participants in a condition that never received a set of List 1 words (a control condition), suggesting that participants instructed to forget List 1 words are performing as if they had never been exposed to the words in the first place (e.g., Bjork, Bjork, & Anderson, 1998).

Why are humans proficient at intentionally forgetting? Knowledge structures often create competition that requires the suppression of irrelevant information (i.e., forgetting) to better facilitate the retrieval of relevant information (e.g., Bjork, 1970; Bjork, 1989; James, 1890; Storm, Bjork, Bjork, & Nestojko, 2006). From a cognitive perspective, the term "relevant", describes retrieved information that is currently useful or will be used in the future to accomplish a task or goal. However, from a social psychology perspective, the term relevant describes information that serves an important motivational function to the self. Hence, there may exist situations where task values align with important motivational processes and lead individuals to forget information.

1.1. Motivated forgetting as an individual differences factor

The aforementioned directed-forgetting research establishes that individuals can be externally directed to forget. But might there be situations in which individuals self-impose an internal directive (or motive) to forget? A threat-based model of motivated forgetting argues that unpleasant, threatening, or painful experiences can lead some

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individuals to forget memories of such experiences in an effort to protect the self. Motivated forgetting is argued to help enhance one's well-being and mental health by protecting individuals against unpleasant memories (e.g., Anderson & Green, 2001; Conway & Pleydell-Pearce, 2000; DePrince et al., 2012). But individuals do not indiscriminately forget all unpleasant events. Rather, individuals forget (i.e., mentally protect against) memories or experiences that call into question the self-perceptions one is trying to maintain (e.g., Rapaport, Schafer, & Gill, 1946; Turner & Barlow, 1951).

Research, across a variety of disciplines, finds that individuals who hold a favorable perception of themselves also are much more likely to react defensively against threats that challenge those perceptions (Baumeister, Smart, & Boden, 1996; Jones, Pelham, Mirenberg, & Hetts, 2002). For example, when people are given feedback, they selectively forget negative, but not positive feedback, especially when it concerns attributes central to the self as opposed to feedback on attributes that are not central to the self (Green & Sedikides, 2004; Newman, Eccleston, & Oikawa, 2017). Similarly, students who highly identify with their university forget more information when they are presented with information that calls into question the academic status of their university, as compared with students who do not identify with their university (Dalton & Huang, 2014). People also are more likely to forget statements from historical passages when those statements describe atrocities committed by a specific cultural group with whom they identify (i.e., American settler) and not by a cultural group that is distant to their identity (i.e., European settler; Imhoff & Banse, 2009; Rotella & Richeson, 2013; Sahdra & Ross, 2007). We note that the literature has used different terms to describe one's self-concept including perceptions, identity, self-perception, and self-image. While these terms are not identical, they all index people's evaluation of their ability in an academic area. Here, we use the more broad term “self-concept” to describe the extent to which individuals hold a predominantly positive mental representation of themselves for a particular domain (Baumeister, 1998).

Why would holding a higher self-concept increase one's vulnerability to threat? Self-Affirmation Theory argues that individuals are motivated to maintain their self-integrity by viewing themselves as good, capable, and worthy (Aronson et al., 1999; Sherman & Cohen, 2006). In the context of education, disfluent learning experiences (i.e., extremely difficult tasks, negative comments, stress and anxiety) in a valued domain can feel quite threatening to students who are motivated to feel capable. These experiences can produce a defensive response that is designed to ultimately minimize the threat. Individuals can respond to these threats using a variety of protective biases that alter attitudes, behaviors, attention, as well as memory processes such as forgetting. Threat-based theories suggest that individual differences in factors that create disfluent learning experiences and high domain-specific self-concept might serve as key ingredients in creating a defensive reaction that leads to forgetting. Hence, even though motivated forgetting is meant to be protective, we wondered whether it also might come at an unintended cost when it occurs for educationally relevant content.

1.2. Motivated forgetting in education

Learning and memory maintenance within educational contexts can be shaped by a variety of competing experiences. For instance, college students develop their intellectual and domain self-concept in a highly stressful environment that often challenges the self-concept they developed during high school (Marsh & Parker, 1984). Several examples of motivated forgetting have been demonstrated for educationally relevant material. For instance, threatening experiences have been found to lead students to forget historical passages (Rotella & Richeson, 2013), personal STEM perceptions (Major, Spencer, Schmader, Wolfe, & Crocker, 1998; Nussbaum & Steele, 2007; Osborne, 1997), and ability judgments (Necka, Sokolowski, & Lyons, 2015).

One recent study asked whether stressful classroom experiences might lead college students to forget math content once the course was over. Ramirez, McDonough, and Jin (2017) began by measuring individual differences in students' math self-concept at the beginning of an academic quarter. They then asked students to report every week how much course stress they experienced. Individual differences in math self-concept positively predicted performance on the final exam, consistent with intuitive notions that math self-concepts are rooted in students' true math ability. However, neither average course stress nor the interaction between average course stress and math self-concept predicted how well students performed on the final exam, presumably because students felt it was unwise to forget course relevant content when they were still participating in the course. The novel finding of this study was revealed two weeks after the course was over: Students with high math self-concept who reported undergoing a stressful course experience exhibited the largest drop in exam performance (i.e., the most forgetting) and even reported that they actively avoided thinking of the course within that two-week time span after the course was over. Ongoing stress was argued to challenge the math self-concept students wanted to maintain, which created a motivation to forget the experience surrounding the course at a time that was most opportune—the summer break. Thus, this study suggests that acute stress is a critical factor that leads to forgetting selectively for students with high math self-concept.

1.3. The relationship between math self-concept and math anxiety

Whereas the aforementioned study by Ramirez et al. (2017) tested the combined influence of math self-concept and course-related stress on forgetting of math content, it also could be the case that trait-related factors, such as math anxiety, enhance defensive mechanisms of forgetting as well. Math anxiety can be defined as a fear or apprehension for situations that involve math. Math anxiety harms math outcomes by creating worries that disrupt working memory and contribute to disfluent learning (Vukovic, Kieffer, Bailey, & Harari, 2013) and performance experiences (Ashcraft & Kirk, 2001). Math anxiety also creates a tendency to avoid experiences that might involve math (Hembree, 1990).

Critically, math anxiety has been shown to be related to, but distinct from, math self-concept (Bai, Wang, Pan, & Frey, 2009; Krinzinger, Kaufmann, & Willmes, 2009). Math anxiety is not synonymous to feeling threatened in the domain of math as some math anxious individuals also are low in math self-concept (Ahmed, Minnaert, Kuyper, & van der Werf, 2012; Jameson, 2014). We also observe that a high degree of math anxiety is found even among individuals with relatively high math self-concept, high math competency, and greater math education (Foley et al., 2017; Hembree, 1990; Ramirez, 2017). Nevertheless, when considering the acute affective reactions and disfluent performance caused by math anxiety, people with high math self-concept may be particularly vulnerable to experiencing threat and subsequent threat-based motivated forgetting. Current evidence suggests that the interaction between math anxiety and math self-concept can create threat-based defensive reactions that lead college students to distort their skill level (Necka et al., 2015) and reduce children's learning across a school year (Ramirez, 2017).

1.4. Current study

The present study builds on previous research to test whether individual differences in math self-concept and math anxiety interact to create threat-based motivated forgetting of math-relevant material. A major assumption made by much of the previous work on motivated forgetting in math is that students only give in to their motivation to forget at opportune times (e.g., during an academic break period, at the end of a research study). This research has assumed that when the learned content is perceived to be irrelevant, students will give in to

their motivation to forget. Here, we merge concepts from threat-based motivated forgetting research with more traditional directed-forgetting research to demonstrate the effects of intentional and motivated forgetting in shaping memory outcomes.

Understanding how threat-based motivated forgetting processes work in conjunction with directed forgetting in the laboratory has promise to help researchers and educators devise ways to minimize forgetting in educational contexts. Examining a threat-based model of motivated forgetting in a controlled laboratory environment allows us to reduce the added sources of noise that could have impacted the forgetting rates observed in previous fieldwork. For instance, field research that assesses exam performance cannot fully account for the background knowledge that students bring to the classroom, including the amount needed to study course-related information. As detailed below, the present study makes use of basic math-related words and algebraic word problems at a 7th grade level to minimize background knowledge.

Additionally, one common obstacle encountered by much of the previous research on motivated forgetting has been in ruling out a "deficient-encoding hypothesis" (e.g., Appel, Kronberger, & Aronson, 2011; Sedikides, Green, & Pinter, 2004). This account suggests that a sense of threat leads students to process information in a superficial manner, thus leading to poor memory performance. Thus, the deficient-encoding hypothesis suggests that poor encoding leads to poor memory rather than an active forgetting process after information has been encoded well. For instance, some participants may simply spend less time studying for material that might threaten their self-concept. Avoidance-related processes are a hallmark of anxiety and are difficult to control in a field study. While participants can still engage in deficient encoding in a basic laboratory study, these effects are greatly minimized by keeping the length of the study episodes constant across all participants.

In the present study, participants first reported their level of math anxiety and math self-concept. Participants then solved algebraic word problems that required knowledge of fractions to activate anxiety towards math. Moreover, participants were told that these word problems were a preview of what would come later in the experiment, so as to help sustain potential math anxiety levels until the end of the study. Participants then followed a directed-forgetting protocol, which uses external directives to cue participants to either remember or forget the learned material.

Our primary hypothesis was that individuals who were vulnerable to threat-based motivated forgetting (i.e., those high in both math self-concept and math anxiety) would be more likely to forget a list of math-related words when they were told to do so explicitly (the forget condition), but not when they were explicitly told to remember (the remember condition). We reasoned that, in a context that coheres with participants' own intentions to forget (the forget condition), participants with high math anxiety and high math self-concept would have the internal motivation to most effectively carry out the directed-forgetting instructions on the list of math-related words learned. In contrast, participants would not give in to their motivation to forget when they received explicit instructions to remember that information (the remember condition). In this way, we examined how external directives to forget work in conjunction with internal motivations to forget within the domain of math.

On the other hand, a deficient-encoding account would be supported if we found that individuals high in both math self-concept and math anxiety are more likely to forget a list of math-related words even in the remember condition compared to all other individuals. As an additional test of this account, we included a third condition that presented participants with one list of words to be remembered (list 2) to minimize complex interactions that might result from the first and second lists interfering with one another. If individuals under threat are encoding material in a deficient manner, then we should expect reduced recall of list 2 words for individuals high in both math self-concept and math anxiety even when no explicit instructions to remember or forget were provided.

In exploratory analyses, we tested whether potential forgetting effects would spread to forgetting of information for which we directed participants neither to remember nor to forget (i.e., the initial algebraic word problem solutions). At least two intriguing possible outcomes were foreseen. One possibility was that all participants under threat (i.e., those with high math anxiety and high math self-concept) would forget, regardless of the forget/remember instructions. This outcome would suggest that moving on to a new task creates the perception that it is acceptable to forget. A second possibility was that participants under threat would only forget when external directives to forget were given as part of the directed-forgetting paradigm. The latter finding would suggest that external directives to forget could generalize beyond what individuals were specifically directed to forget.

2. Materials and methods

2.1. Participants

This study was carried out in accordance with the human subject's guidelines of the Institutional Review Board at University of California, Los Angeles. Participants (N = 181) were recruited through the psychology subject pool for course credit and through flyers posted on campus for $10. We excluded 9 participants who indicated that they did not clearly understand the instructions and 2 participants that did not complete the study, leaving 170 participants (127 female, age range = 18–33). Participants were randomly assigned to one of three conditions: Forget-Remember condition (n = 56), Remember-Remember condition (n = 54), and Shape Discrimination-Remember (control) condition (n = 60).

2.2. Design and materials

The study consisted of four phases (see Fig. 1). First, demographic and individual differences measures were assessed (survey phase). Second, participants solved algebraic word problems to trigger and sustain their anxiety (algebraic problem-solving phase). We also used the responses to these algebraic word problems as a part of a surprise memory test (described below). Third, a list-method directed-forgetting paradigm was implemented using math-related words (directed-forgetting phase). The list-method refers to the fact that remember and forget cues were given following a study period of an entire list of words and contrasts to the item-method, in which remember and forget cues are presented immediately after each word is presented. Lastly, participants were asked to recall the equations to the three algebraic word problems they solved during the algebraic problem-solving phase.

The individual difference measures consisted of math self-concept and math anxiety. Math self-concept was assessed using two items that have been used in prior research (e.g., Beilock, Rydell, & McConnell, 2007; Markus, 1977). The two items were "It is important to me that I am good at math" and "I am good at math" and rated on a 7-point Likert scale. Math anxiety was assessed using the Abbreviated Math Anxiety Scale (AMAS) that consisted of 9 items rated on a 5-point Likert scale (Hopko, Mahadevan, Bare, & Hunt, 2003).

The algebraic problem-solving phase consisted of three algebraic word problems. For example, *Maria had n boxes, and she bought seven more boxes. A week later, half of all of her boxes were destroyed in a fire. Fortunately, the fire was put out before it damaged her furniture. There are now only 22 boxes left*. Participants were asked to enter an algebraic equation as quickly as possible (e.g., $n + 7 = 22x$, $n = 22 \times 2–7$).

The directed-forgetting phase consisted of three between-subject conditions (Forget-Remember; Remember-Remember; Shape Discrimination-Remember). In the first two conditions (Forget-Remember and Remember-Remember), participants were presented with two word lists that each contained 12 math-related words. Two

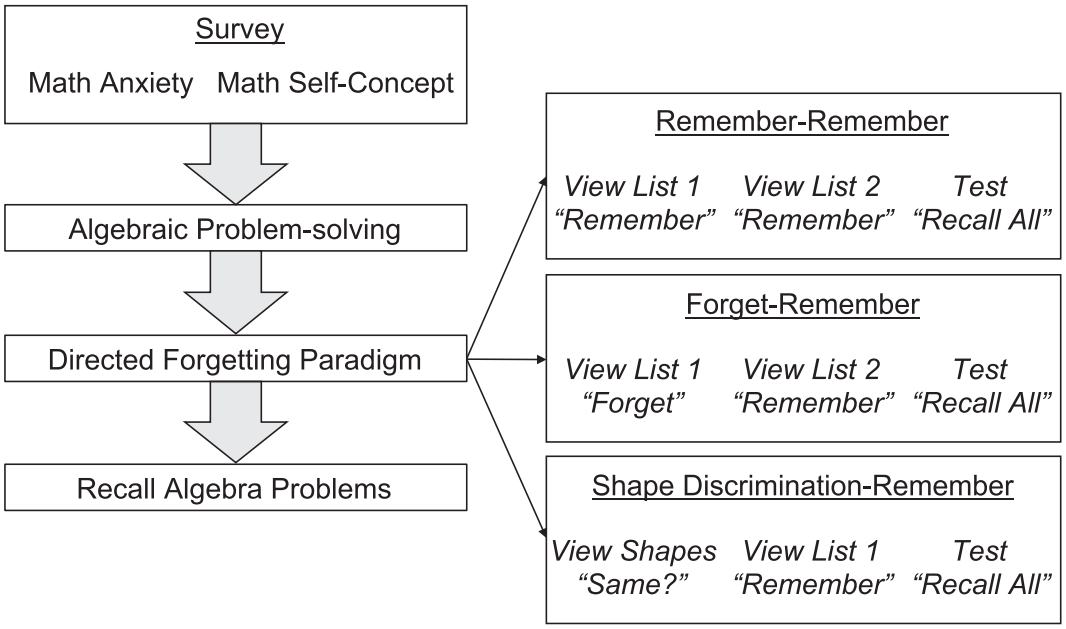

Fig. 1. Schematic of procedure.

different versions of each condition were created to counterbalance the order of the first and second list. Pilot testing in a separate sample of participants revealed that these words were familiar yet relatively unpleasant (see Appendix A). Participants in the Shape Discrimination-Remember condition were asked to make simple judgments on a set of common shapes (e.g., circles and squares) in the first block and a list of words to remember in the second block.

Both the Remember-Remember and the Shape Discrimination-Remember conditions helped to evaluate a deficient-encoding account of motivated forgetting. If participants with both high math anxiety and high math self-concept encode the list of math-related words in a superficial manner, then we should expect that they should demonstrate reduced recall across all conditions. Furthermore, the Remember-Remember condition allowed us to understand how individual differences in math anxiety and math self-concept impact both the "costs" of forgetting (for List 1) and the "benefits" of forgetting (for List 2) as mentioned in the Introduction.

2.3. Procedure

Participants were tested in groups of two to three people at a time. They first filled out demographic information and took surveys to assess their math self-concept and math anxiety. Participants were then given instructions that explained the preliminary algebraic word problems and the directed forgetting paradigm.

Participants then proceeded to complete the algebraic problem-solving phase. Problems were displayed one at a time, with the instructions that the participants should complete the problems as quickly as possible. The goal of presenting participants with algebraic word problems was to create a heightened state of anxiety for the main study and to test whether participants under threat would forget the answers, even if they never received explicit forget instructions. This task was introduced to participants as a preview of the types of problems they might encounter in a later portion of the experiment. Hence, as far as participants were concerned, the relevance of the items encountered during the algebraic problem-solving phase ended as soon as the task was over. One would expect that if our manipulation was successful in inducing anxiety, then math anxious participants would show overall poorer performance on the algebraic word problems. We found a significant negative correlation between degree of math anxiety and algebraic word problem accuracy (r (168) = −0.18, p = .018), supporting this notion.

During the directed-forgetting phase, participants viewed a list of 12 math-related words one at a time for 3 s (Block 1). After studying all of the words in Block 1, participants in the Forget-Remember condition were told that they had just finished a practice block, and they should forget the previous list of words because those words would not be tested later. Participants in the Remember-Remember condition were told that they should remember the block of words they just saw and that they would be later tested on those words. Participants in the Shape Discrimination-Remember condition viewed common shapes (e.g., circles and squares) in different colors during Block 1 and were asked to make a judgment as to whether the two objects were identical in shape ("yes" or "no"). Twelve pairs of objects were presented one at a time for 3 s.

In all conditions, participants were then told that they would view a new list of words that they needed to remember for a later memory test (Block 2). Following Block 2, participants were given 10 min to recall all previously presented words in any order, even if they were told to previously forget the words. At the end of the 10 min, participants were asked to recall the algebraic equations that were previously provided in their attempt to solve the three algebraic word problems. Lastly, participants were asked to indicate how clear the instructions were on a 4-point Likert scale.

3. Results

Analyses were conducted using R version 3.3.1 (Research Core Team, 2013). Sex was used as a covariate in all subsequent analyses because sex differences have been previously reported in math anxiety (Goetz, Bieg, Lüdtke, Pekrun, & Hall, 2013), verbal memory (e.g., Herlitz, Nilsson, & Bäckman, 1997; Kerschbaum et al., 2017; Lewin, Wolgers, & Herlitz, 2001), and math (e.g., Beilock, Gunderson, Ramirez, & Levine, 2010; Spencer, Steele, & Quinn, 1999). We first report the omnibus directed-forgetting effects, which compares recall performance in the Forget-Remember condition to the Remember-Remember condition. Separate analyses were conducted for recall of the math-related word lists and recall of the algebraic word problems. These analyses were conducted to confirm that we replicated the directed-forgetting effects across all participants and to explore any

general effects that forgetting instructions might have had on the algebraic word problems.

We then report analyses that test our primary hypotheses that concerned individual difference effects of math anxiety and math self-concept. We tested the math anxiety x math self-concept interactions within the Forget-Remember condition first, followed by the same interaction in the Remember-Remember condition, and the Shape Discrimination-Remember condition. To best understand the forgetting effects, we carried out analyses on four different dependent variables: the proportion of words recalled in Block 1, the proportion of words recalled in Block 2, a net forgetting score (i.e., proportion recalled in Block 2 – proportion recalled in Block 1),[1] and recall of the algebraic solutions. Because the Shape Discrimination-Remember condition did not include a recall portion for Block 1, we did not include this condition in analyses that included Block 1 or the net forgetting scores.

One-tailed tests were used for the overall directed forgetting effects and the math anxiety x math self-concept interactions in the Remember-Forget condition because each were clearly predicted by previous research (Bjork et al., 1998; Ramirez et al., 2017). The other tests were more exploratory and so relied on two-tailed tests.

3.1. Omnibus directed forgetting effects

We first report our attempt to replicate previous findings using the directed-forgetting paradigm, which included the forgetting effects in Block 1 and facilitation effects in Block 2. We used a 2 (Block) × 2 (Condition) Analysis of Covariance (ANCOVA) to analyze the data. Block was a repeated measures factor with two levels (the first block of words and the second block of words) while Condition was a between-group factor with two levels (instructions to forget, instructions to remember). Sex served as a covariate. Our dependent variable was the proportion of words correctly recalled. Results revealed a main effect of Condition, $F(1, 107) = 3.47$, $p = .033$, such that those in the Remember-Remember condition recalled more words overall than the Forget-Remember condition ($M = 0.49$, $SE = 0.019$ and $M = 0.44$, $SE = 0.019$ for each condition, respectively). We did not, however, find a main effect of Block ($p > .05$). Critically, we also found a Block × Condition interaction, $F(1, 107) = 35.87$, $p < .001$. Independent *t*-tests were conducted between the Forget-Remember and Remember-Remember conditions to break down this interaction. As expected, participants in the Forget-Remember condition showed greater forgetting in Block 1 than participants in the Remember-Remember condition, $t(107) = 5.49$, $p < .001$ (Table 1). Participants in the Forget-Remember condition showed greater facilitation effects in Block 2 than participants in the Remember-Remember condition, $t(107) = 1.83$, $p = .018$.

Net forgetting effects were calculated by subtracting Block 1 memory performance from Block 2 memory performance. Positive forgetting scores indicate a larger forgetting effect. The forgetting score was greater for participants in the Forget-Remember condition than those in the Remember-Remember condition, $t(107) = 5.99$, $p < .001$. Thus, we replicated standard directed forgetting effects between the Forget-Remember and Remember-Remember conditions. We also examined whether there was an omnibus effect of condition on participant's recall of the algebraic word problems. As a reminder, we first began the study by presenting participants with a set of algebraic word problems for which they were instructed to generate an algebraic expression, and then we subsequently presented participants with two blocks of words. Those in the Forget-Remember condition were given a cue to forget the first block of words while those in the Remember-Remember condition were given a cue to remember the first block of words. We then asked participants to recall all of the words they were presented with and also instructed participants to recall the algebraic expressions they generated. To test whether the directed-forgetting instructions generalized to the forgetting of the algebraic word problems, we conducted a one-way ANCOVA on recall for the algebraic word problems. This analysis consisted of one between-subjects factor with three levels of Condition (Forget-Remember, Remember-Remember, Shape Discrimination-Remember) and sex as a covariate. The effect of Condition was not significant, $F(2, 166) = 1.23$, $p > .31$. This analysis provides no evidence for the notion that directed-forgetting instructions across all groups impacted recall for the algebraic word problems, which never received instructions to either remember or forget. We next report our primary analyses regarding the effects of math anxiety and math self-concept for each block in the Forget-Remember condition.

Table 1
Means and standard deviation of proportion recalled across blocks as a function of condition.

Condition	Block 1		Block 2		Forgetting score	
	M	SD	M	SD	M	SD
Forget-Remember	.38	.16	.51	.17	.13	.20
Remember-Remember	.55	.15	.44	.20	−.10	.20
Shape Discrimination-Remember	–	–	.67	.14	–	–

Note: Forgetting score was calculated by subtracting Block 1 from Block 2 such that positive scores indicate a larger forgetting effect.

3.2. Forget-Remember condition as a function of math anxiety and math self-concept

Here, we tested whether individual differences in math anxiety and math self-concept moderated the results in the Forget-Remember condition. Multiple regression analyses were conducted with math anxiety as the independent variable and math self-concept as the moderator variable, with both treated continuously. Four separate multiple regression analyses were conducted for each dependent variable: proportion of words recalled in Block 1, proportion of words recalled in Block 2, a net forgetting score, and recall of algebraic word problems. The independent variables were standardized before entering them in the analyses.

For the proportion of words recalled in Block 1, no significant main effects or interactions were found (all $ps > .06$). For the proportion of words recalled in Block 2, we also did not find any significant main effects or interactions (all $ps > .28$). In terms of the net forgetting score, we also did not find significant main effects (all $ps > .08$), but we did observe a significant math anxiety x math self-concept interaction ($\beta = 0.049$, $SE = 0.026$, $p = .034$; Fig. 2A). A simple slopes analysis revealed a significant positive slope between math anxiety and the forgetting score for participants who were high in math self-concept ($\beta = 0.085$, $SE = 0.038$, $p = .014$), but not for participants who were average or low in math self-concept ($ps > .10$). These effects suggest that individuals high in math anxiety who also have high math self-concept have the largest net forgetting effects.

To test whether individuals who are motivated to forget might generalize explicit instructions to forget, we conducted the same math anxiety x math self-concept interaction on participants' ability to recall the answers for the algebraic word problems. Overall means for recall of the algebraic expressions can be found in Table 2. Because this analysis was exploratory, we used a two-tailed test. The interaction between math anxiety and math self-concept was marginally significant ($\beta = -0.26$, $SE = 0.14$, $p = .061$), but in the same direction as the effects of recall for math-related words; Individuals with both higher math anxiety and higher math self-concept numerically showed poorer

[1] We calculated a net forgetting score to facilitate the interpretation of the between group differences. Because the directed forgetting produces both costs and benefits (forgetting of Block 1 and greater memory of Block 2), a net forgetting score is helpful in seeing the totality of the manipulation in a single score.

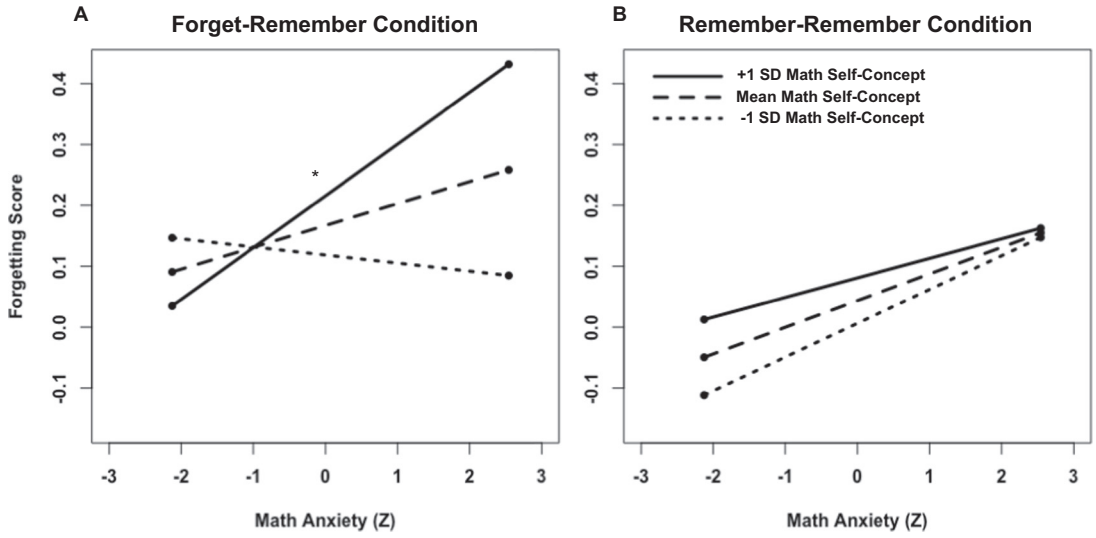

Fig. 2. Forgetting score in the Forget-Remember and Remember-Remember conditions as a function of math anxiety and math self-concept. Normalized math anxiety is presented on the x-axis and Forgetting Score (proportion recalled in Block 2 minus proportion recalled in Block 1) is presented on the y-axis. For the Forget-Remember condition (Panel A), individuals one standard deviation above the mean on math self-concept showed a significantly positive association with levels of math anxiety and forgetting score. In contrast, for individuals with average math self-concept and one standard deviation below the mean of math self-concept, there was no significant difference in math anxiety and the forgetting score in this condition. For the Remember-Remember Condition (Panel B), none of the slopes were significant. * $p < .05$.

Table 2
Means and standard deviation for recall of the word problems as a function of condition.

Condition	M	SD
Forget-Remember	1.45	.99
Remember-Remember	1.46	.91
Shape Discrimination-Remember	1.70	1.08

Note: Mean recall for the word problems did not differ between groups, *ps* > .19.

memory for the math problems (see Fig. 3A). No significant main effects were found (*ps* > .32). When controlling for student's accuracy on the algebraic word problems, our results for the math anxiety x math self-concept interaction remained unchanged ($\beta = -0.27$, $SE = 0.14$, $p = .054$). A simple slopes analysis indicated that, for participants higher in math self-concept, higher math anxiety was associated with reduced recall ability for the algebraic expressions ($\beta = -0.36$, $SE = 0.20$, $p = .071$). The slopes for mean levels of math self-concept and low math self-concept were not significant (*ps* > .38).

3.3. Remember-Remember condition as a function of math anxiety and math self-concept

We next tested the extent to which the individual differences in math anxiety and math self-concept also occurred in the Remember-Remember condition. Because these analyses were more exploratory and were not directly predicted based on prior research, we used two-tailed tests. For memory in Block 1, no significant main effects or interactions were found (*ps* > .12). For memory in Block 2, we found a significant main effect of math self-concept ($\beta = 0.12$, $SE = 0.060$, $p = .049$) such that greater math self-concept was associated with

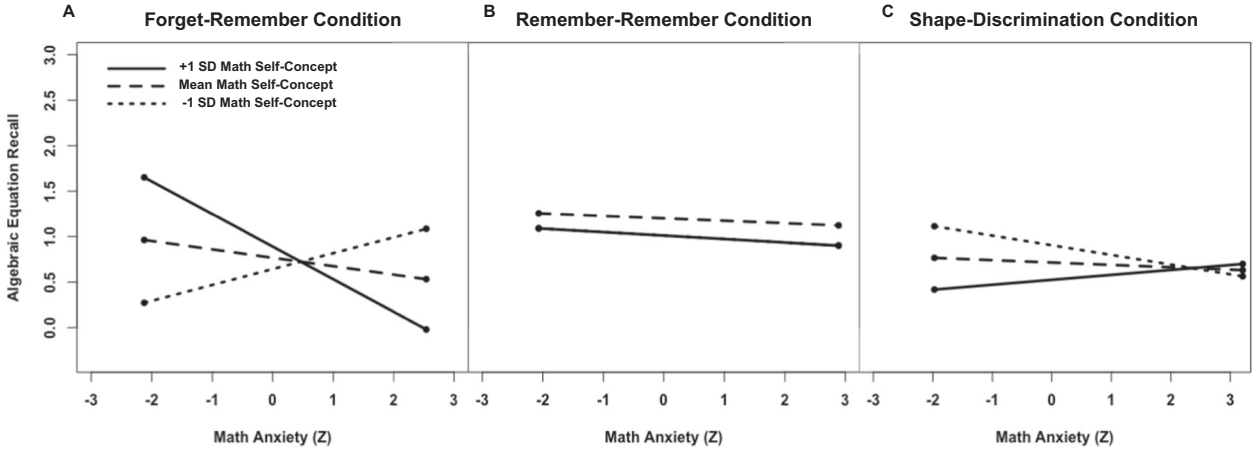

Fig. 3. Recall of the algebraic equations as a function of math anxiety and math self-concept for each condition. Normalized math anxiety is presented on the x-axis and the number of recalled algebraic equations from the second phase of the study is presented on the y-axis. The solid lines represent people with math self-concept one standard deviation above the mean, the dashed lines represent people with average math self-concept, and the dotted lines represent people with math self-concept one standard deviation below the mean. For individuals one standard deviation above the mean on math self-concept, higher levels of math anxiety were associated with marginally poorer recall of the algebraic equations out of 3 in the Forget-Remember condition. No other differences approached significance. Accuracy of solving the algebraic equations in the second phase of the experiment was controlled in this analysis.

better memory in Block 2. No other main effects or interactions were found for Block 2 (*ps* > .08). For the net forgetting score, no main effects or interactions were significant (*ps* > .19). These findings suggest that participants high in both math anxiety and math self-concept do not have a general tendency to have poor memory performance as would be suggested by a deficient-encoding account. More importantly, this finding also suggests that cues to forget are critical to lead to forgetting among individuals who might be experiencing threat. Lastly, we tested whether the math anxiety x math self-concept interaction would be observed on the memory for the algebraic expressions presented during the algebraic problem-solving phase. No significant effects were found (*ps* > .29).

3.4. Shape Discrimination condition as a function of math anxiety and math self-concept

In prior directed-forgetting studies, researchers have used control conditions that do not put prior demands on memory as a means of comparing Block 2 performance with the Forget-Remember condition (e.g., Bjork et al., 1998). Using this control condition serves as a second test of the deficient-encoding account. We conducted the same regression using math anxiety as the independent variable, math self-concept as the moderator variable, and sex as a covariate on the proportion of words recalled. We found no main effects or an interaction (*ps* > .38) using any of the math list word outcomes. Lastly, no significant effects were found on the memory for the algebraic word problems (*ps* > .13). Thus, no support was found for the encoding-deficiency account.

4. Discussion

Students commonly contend with maintaining memories for educationally-relevant content, even if their course-relevant experiences were unpleasant. The current study examined motivated forgetting of math-related material within a controlled laboratory environment using a directed-forgetting paradigm to test the extent that defensive motives work in conjunction with external motives to forget. We found that participants who were both high in math anxiety and high in math self-concept exhibited greater forgetting for math-related words when instructed to forget (i.e., the forget condition) compared with 1) those lower in math anxiety, 2) those who had low math self-concept, and 3) all participants who were not encouraged to forget (i.e., participants in the Remember-Remember and Shape Discrimination-Remember conditions). These findings replicate and extend related field research by showing that motivated forgetting occurs for students experiencing threat and within a context where forgetting cues are provided.

Participants under threat were most likely to forget the math-relevant words when directed to do so (i.e., the Forget-Remember condition), but not when they were directed to remember the words. We suspect that when participants were directed to forget, this external directive worked in conjunction with the participants' own internal motivation to forget their experiences. Our results suggest that participants under threat do not simply submit to their motives, but rather look for opportune times when they perceive it is acceptable to forget. For instance, students under threat have been shown to wait until the summer and winter break periods to give into their motivation to forget (e.g., Ramirez, 2017; Ramirez et al., 2017). Students also forget course material when given non-cumulative exams, which cue students that the previous material is no longer relevant (e.g., Khanna, Brack, & Finken, 2013; Lawrence, 2013).

Interestingly, we found that participants under threat also tended to forget the algebraic expressions they generated during the algebraic problem-solving phase—although this effect was only marginally significant. What makes this finding particularly noteworthy is that the participants never received a cue to either remember or forget the solutions they provided to the algebra word problems. Rather, they only received instructions to forget the word list that followed the algebraic word problems. The results for the algebraic word problems suggests that external directives to forget can generalize broadly for people experiencing threat-based motivated forgetting. The explicit forget instructions participants received as a part of the directed-forgetting paradigm may have worked in line with their own motivations to forget everything they had previously encountered in the experiment up to that point. Another possibility is that participants who completed the algebraic problem-solving phase thought they were done with that portion of the experiment, which may have created an implicit cue to forget. But if this were the case, we should have observed threat-based forgetting effects for the algebraic expressions for students participating in the other conditions as well, which was not the case. Our results suggest that participants' forgetting has the potential to generalize to more extended situations than previously thought.

While directed forgetting often has been couched as a willful and adaptive process, the present study suggests that being anxious about math, despite having high self-concept related to math, might create a threat that students attempt to resolve by forgetting the experiences that led to their threat experience. Hence, motivated forgetting may serve a beneficial role in helping students repair how they view themselves, a role which would have important interpersonal benefits. However, within the context of education, those who engage in motivated forgetting of content may be putting their knowledge and future career performance at a disadvantage by not being able to readily recall important math ideas and procedures.

An alternative explanation for the main findings we report here is that individuals with both high math anxiety and high math self-concept encoded the math-related words more poorly, also known as the deficient-encoding hypothesis (e.g., Appel et al., 2011; Sedikides et al., 2004). There are several reasons why we think a deficient-encoding hypothesis cannot explain our results. First, all participants received the same information for the same duration of time, which limits the extent to which people can engage in avoidance processes that lead to deficient encoding found in other situations. We also did not find evidence for a math anxiety x math self-concept interaction in the Remember-Remember or Shape Discrimination-Remember conditions, the results of which suggest that participants under threat were not simply encoding the material in a deficient manner.

Instead, our results align well with either an inhibitory account or a context change account of directed forgetting. According to an inhibitory account, active cognitive control processes can be directed to temporarily suppress or deactivate that information's representation in memory, thus causing a loss of access (e.g., Bjork et al., 1998). People that are both highly math anxious and have a high math self-concept might be motivated to exercise these cognitive control processes when faced with a negative math experience, especially when permitted to forget that experience. According to a context change account, receiving a forget cue creates a new mental context (Manning et al., 2016; Sahakyan & Kelley, 2002), which creates a new set of cues to aid in the memory search process. The larger the degree of mental shift, the more likely the current set of cues will not overlap with the past cues, thus making retrieval more difficult. In regard to the present study, the forget cue may have caused participants with both high math anxiety and high math self-concept to shift their mental context, thus causing them to have a mismatch between past cues and the current cues. Consistent with this idea, Ramirez et al. (2017) found that students high in math self-concept were more likely to avoid thinking about their previous math course if they experienced a stressful course experience. Whichever the mechanism, the present study hints that the cues to forget impacted the list of math-related words and answers for the algebraic word problems. However, with only three algebraic expressions, we likely lacked the sensitivity to find strong effects.

The present findings also are consistent with other motivated forgetting research in non-learning contexts. For example, Dalton and Huang (2014) had university students view advertisements linked to their university identity and then threatened that identity using a

negative (fictitious) news article. They found that students who were both threatened and highly identified with their university were more likely to forget the advertisements compared with the other conditions in their study. They also found that this forgetting selectively impaired memory for specific details, rather than more automatic forms of memory such as feelings of familiarity (e.g., Yonelinas & Jacoby, 2012). Because the present study used free recall to test memory (which is thought to rely on recollection-like processes more than familiarity-like processes), we could not estimate whether individuals high in math anxiety and math self-concept retained a sense of familiarity with the math-related words. Based on the Dalton and Huang (2014) study, we speculate that familiarity for the math-related words would remain intact.

While the present study highlights the costs of forgetting for educationally-relevant content, other research suggests ways to prevent such cases of motivated forgetting. Three conditions appear necessary to induce motivated forgetting. First, people with favorable concept of themselves in a given domain seem to be particularly susceptible to reacting defensively against experiences that might call such their self-concept into question (Baumeister et al., 1996). Research on self-affirmation suggests that one way to combat the defensive reactions that arise out of threat is to restore an individual's global sense of integrity by having the individual focus on other valued domains. Another approach to combat identity threat is to teach individuals that domain identity and disfluent learning experiences are not mutually exclusive and often promote positive growth (Lin-Siegler, Ahn, Chen, Fang, & Luna-Lucero, 2016). Second, people must experience a high degree of stress or anxiety (as shown in the present study), both of which can challenge the perceptions that individuals are motivated to maintain. By attempting to reframe stress and anxiety as a positive (i.e., energizing) rather than negative (i.e., disruptive) experience, people may be more likely to view disfluent learning experiences as a challenge rather than as a threat (Jamieson, Mendes, & Nock, 2013).

Lastly, cues or directives to forget seem to be important triggers to motivated forgetting. While the present study employed explicit cues to forget, previous motivated forgetting research demonstrates that participants themselves can internally “direct” themselves to forget when it seems advantageous to do so such as at the end of a study or course (for discussion, see Bjork et al., 1998). Many of these internal directives to forget are unfortunately instantiated by school procedures that employ external signals that it is acceptable to forget. For instance, having a substantial break between courses (e.g., Bahrick & Hall, 1991), relying on a linear versus a spiral curriculum (e.g., Bunce, VandenPlas, & Soulis, 2011), and using noncumulative rather than cumulative exams (e.g., Khanna et al., 2013; Lawrence, 2013) can signal forgetting. By reducing these external or internal cues to forget or helping to better signal to students the relevance of the material, scientists and educators may be able to improve the extent to which students retain educationally-relevant material. In fact, we showed in the present study that when instructed to *remember* the material, individuals that are both high in math anxiety and high in math self-concept did not show worse recall performance. Together, evidence suggests that one strategy teachers can employ to reduce potential forgetting effects is to explicitly tell students why they should remember the course content after the course is over, perhaps in service of scaffolding learning in subsequent courses.

This study was not without limitations. For instance, our inclusion of algebraic word problems was meant to heighten anxiety and to test the extent that participants generalized the directions to forget. However, we did not include a manipulation check to ensure that individuals higher in math anxiety were, in fact, made anxious by the inclusion of algebraic word problems. Nevertheless, one would expect that if our manipulation were successful in inducing anxiety, then math anxious participants would show poorer performance on the algebraic word problems, overall. Indeed, we found a significant negative correlation between degree of math anxiety and algebraic word problem accuracy, supporting this claim. Our hypothesized threat-based account of motivated forgetting would also have been strengthened if we had assessed participants' subjective sense of threat as a mediator for the effects we have reported.

One also might wonder whether forgetting of math-related words (and algebraic word problems) might transfer to forgetting of math definitions or even entire math concepts. If found to be true, these effects would be truly profound and would suggest that these self-regulation mechanisms to protect oneself from threat would not only lead to forgetting of episodic memories (as shown here), but also forgetting of semantic memories. Previous work has found that students at risk for threat-based motivated forgetting show reduced final exam performance as well as lower growth across the school year (e.g., Ramirez, 2017; Ramirez et al., 2017). Of course, it is an open question as to whether the participants in previous motivated forgetting studies have well-formed knowledge that was being suppressed due to motivated forgetting. We speculate, though, that fundamental math knowledge or basic math concepts may be less susceptible to the types of forgetting induced here due to the fact that episodic and semantic memory systems are often thought to be distinct (e.g., Johnson, 1983; Tulving, 1985), are subserved by different brain regions (e.g., Menon, Boyett-Anderson, Schatzberg, & Reiss, 2002; Wiggs, Weisberg, & Martin, 1998), and thus should operate on different principles. For example, individuals with bilateral hippocampal damage show profound inabilities to remember new episodic information, but the ability to attend school and maintain factual knowledge over time are more or less spared (Vargha-Khadem et al., 1997). Nevertheless, these findings highlight the critical role of individual difference variables and how they might interact to create motivational forces that lead to forgetting of episodic information.

5. Conclusions

In summary, the present findings aid to the growing literature on the nature of forgetting. Individual differences in self-concept and anxiety surrounding a particular domain can serve as internal motivations to more effectively carry out external directives to forget. While forgetting in such cases is often adaptive and can protect one's well-being, this type of forgetting also can have negative consequences such as when it is in a classroom.

Conflicts of interest

None.

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Appendix A

Interval
Variable
Quotient
Perpendicular
Precalculus
Exponent
Factorial
Fraction
Polygon
Numerator
Tangent

Hypotenuse
Intercept
Probability
Statistics
Integer
Theorem
Quadrants
Vector
Trigonometry
Matrix
Geometry
Reciprocal
Minimum

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